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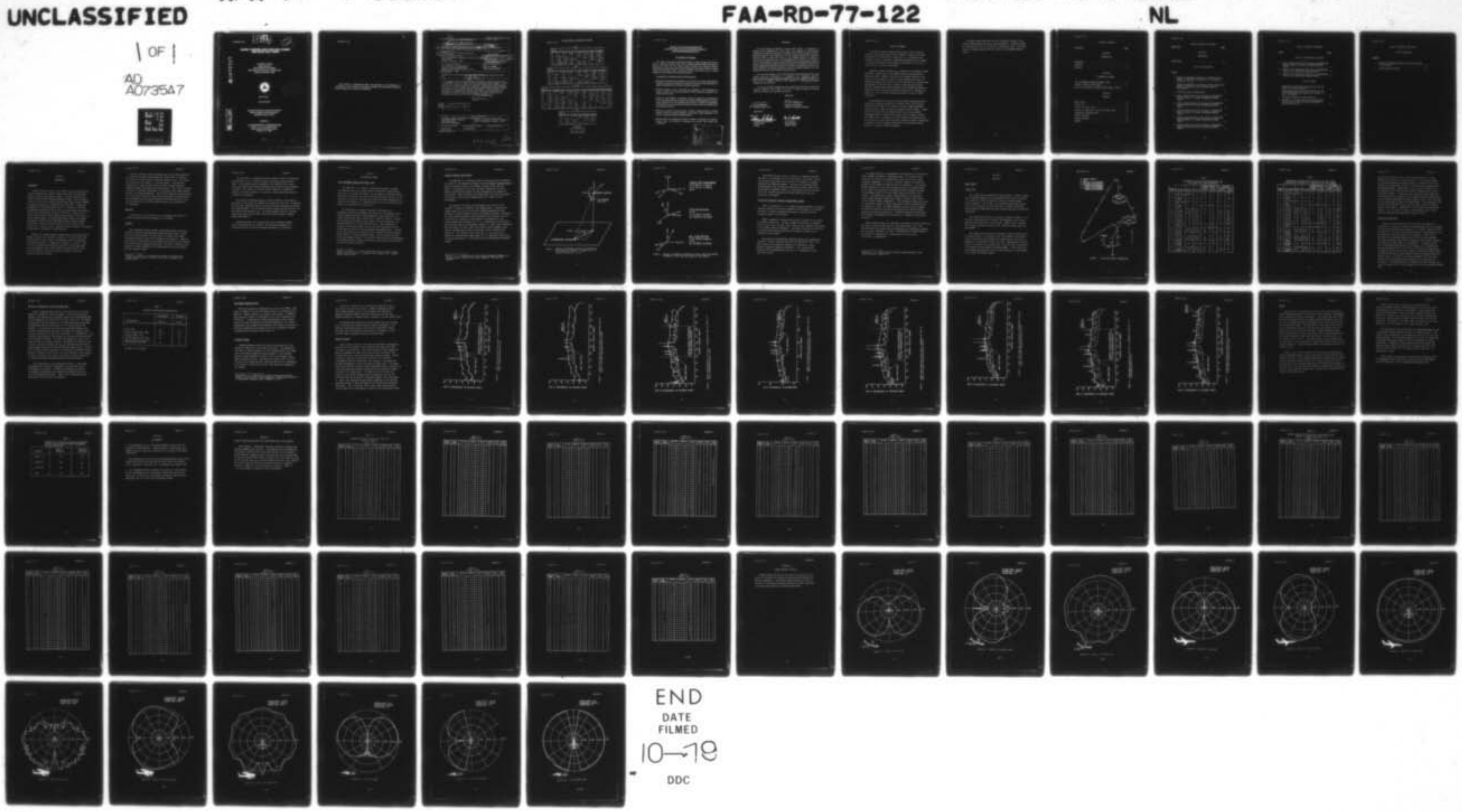

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EVALUATION OF TRANSPONDER ANTENNA COVERAGE/ATCRBS PERFORMANCE DURING SIMULATED FLIGHTS OF AIRCRAFT

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

APRIL 1979

FINAL REPORT

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, DC 20590

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16. Abstract

A computer model was used to analyze the effect of aircraft orientation on the performance of the Air Traffic Control Radar Beacon System (ATCRBS). Flights by Cessna 150, Boeing 727, Boeing 747, and F-4H aircraft over a common flight route out of La Guardia Airport were simulated. Transponder/antenna performance for various aircraft attitudes and locations along the flight path was analyzed with respect to interrogators located at JFK airport. This performance was compared to a transponder having ideal, omni-directional antenna coverage to illustrate the degree to which the combination of aircraft orientation and transponder antenna pattern may affect ATCRBS performance.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	cm	m	km	in	ft	mi	nmi
cm	1	0.01	$1x10^{-5}$	0.3937	0.0328	$6.21x10^{-6}$	$5.39x10^{-6}$
m	100	1	0.001	39.37	3.281	0.0006	0.0005
km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	$2.54x10^{-5}$	1	0.0833	$1.58x10^{-5}$	$1.37x10^{-5}$
ft	30.48	0.3048	$3.05x10^{-4}$	12	1	$1.89x10^{-4}$	$1.64x10^{-4}$
mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	cm^2	m^2	km^2	in^2	ft^2	mi^2	nmi^2
cm^2	1	0.0001	$1x10^{-10}$	0.1550	0.0011	$3.86x10^{-11}$	$5.11x10^{-11}$
m^2	10,000	1	$1x10^{-6}$	1550	10.76	$3.86x10^{-7}$	$5.11x10^{-7}$
km^2	$1x10^{10}$	$1x10^6$	1	$1.55x10^9$	$1.08x10^7$	0.3861	0.2914
in^2	6.452	0.0006	$6.45x10^{-10}$	1	0.0069	$2.49x10^{-10}$	$1.88x10^{-10}$
ft^2	929.0	0.0929	$9.29x10^{-8}$	144	1	$3.59x10^{-8}$	$2.71x10^{-8}$
mi^2	$2.59x10^{10}$	$2.59x10^6$	2.590	$4.01x10^9$	$2.79x10^7$	1	0.7548
nmi^2	$3.43x10^{10}$	$3.43x10^6$	3.432	$5.31x10^9$	$3.70x10^7$	1.325	1

VOLUME

From \ To	cm^3	liter	m^3	in^3	ft^3	yd^3	fl. oz.	fl. pt.	fl. qt.	gal.
cm^3	1	0.001	$1x10^{-6}$	0.0610	$3.53x10^{-5}$	$1.31x10^{-6}$	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^3	$1x10^6$	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	$1.64x10^{-5}$	1	0.0006	$2.14x10^{-5}$	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl. oz.	29.57	0.2957	$2.96x10^{-5}$	1.805	0.0010	$3.87x10^{-5}$	1	0.0625	0.0312	0.0078
fl. pt.	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl. qt.	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal.	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	$1.10x10^{-6}$
kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	$3.12x10^{-5}$
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$°C = 5/9\ (°F - 32)$

$°F = 9/5\ (°C) + 32$

FAA-RD-77-122

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The center, located at North Severn, Annapolis, Maryland 21402, is under policy control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the executive direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-78-C-0006, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center. IIT Resrch Inst

To the extent possible, all abbreviations and symbols used in this report are taken from American Standards Y10.19 (1967) "Units Used in Electrical Science and Electrical *Engineering*" issued by the USA Standards Institute.

Reviewed by:

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THOMAS A. ANDERSON	M. A. SKEATH
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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) relies on the Air Traffic Control Radar Beacon System (ATCRBS) to provide continuous high-quality interference-free input data to its automated surveillance systems. Therefore, dependable performance of the ATCRBS is required to maintain uninterrupted surveillance of all the aircraft in the air traffic environment.

Imperfect antenna coverage is an impediment to dependable ATCRBS operation. Theoretically, the ATCRBS airborne antenna should be omni-directional. However, because of the antenna location on the aircraft, an aircraft in a turn or a bank frequently may have its antenna shielded from the direct line-of-sight path to a ground-based interrogator, which may cause a broken or missing target return. The FAA, needing a better understanding of how ATCRBS performance is affected by aircraft antenna patterns, tasked ECAC to determine the effect of various airborne transponder/antenna systems on ATCRBS performance.

The performance of various aircraft ATCRBS transponder/antenna systems was evaluated using the Air Traffic Control Radar Beacon, Identification-Friend or Foe, Mark XII System (AIMS) Performance Prediction Model (PPM) to analyze simulated aircraft flights. Signal levels received by the interrogators from the various airborne transponder/antenna systems were plotted as the aircraft traversed the flight route. Performance was then compared to predictions for an aircraft with ideal omni-directional antenna coverage to demonstrate the degree to which aircraft orientation, and associated antenna patterns, may affect ATCRBS performance.

The model predictions show that the top-mounted antenna on the F-4H aircraft provides relatively poor performance. Antenna coverage for the Boeing 727 and 747 aircraft was consistently good. Occasional losses in coverage occurred for the Cessna 150 transponder/antenna system.

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Appendix

SECTION 1

INTRODUCTION

BACKGROUND

During the past few years, the Federal Aviation Administration (FAA) has enhanced air traffic control surveillance by providing target tracking, alpha-numeric displays, altitude reporting, and discrete identification through automated systems. These automated systems rely on the Air Traffic Control Radar Beacon System (ATCRBS) to provide high-quality interference-free input data. Dependable performance of the ATCRBS depends upon the reliability with which transponder-equipped aircraft can reply to ground-based interrogators. The FAA and the Department of Defense (DoD) have, through the Air Traffic Control Radar Beacon, Identification-Friend or Foe, Mark XII System (AIMS) program, the ATCRBS Improvement Program, and ATCRBS Interrogator Control and PRF Management Program, improved ATCRBS performance. However, problems relating to the aircraft ATCRBS antenna still concern the FAA. Imperfect antenna coverage is considered an impediment to dependable ATCRBS operation.

Ideally, the ATCRBS airborne antenna should be omni-directional. However, because of the antenna's location on a given aircraft and shielding by the wings, stores, and fuselage, nulls are generated in the antenna pattern. Frequently an aircraft in a turn or a bank will have its antenna shielded from the direct line-of-sight path to an interrogator, which causes broken or missing target returns. This can result in track loss within the automated system and increased controller fatigue.

The FAA, needing a better understanding of how ATCRBS performance is affected by aircraft antenna patterns, tasked ECAC to determine the impact of aircraft antenna radiation characteristics. The results are presented in two reports. A previous report[1] evaluated the suitability of using the Ohio State University antenna synthesis computer program for generating antenna patterns. This report discusses the effect of aircraft orientation, in conjunction with ATCRBS antenna patterns, on ATCRBS performance. The fact that radiation characteristics of the vertically polarized, omni-directional ATCRBS aircraft antennas may be affected by polarization anomalies, wavefront distortion, and coupling effects due to other antennas mounted on the aircraft was not considered.

OBJECTIVE

The objective of this analysis was to determine the effects of aircraft attitude upon the performance of the ATCRBS.

APPROACH

The performance of four aircraft transponder/antenna systems was evaluated using the AIMS Performance Prediction Model (PPM). Flight paths were constructed for the four types of aircraft with ATCRBS transponder/antenna systems to be evaluated in the analysis. Heading, pitch, and roll angles were used to define the position of each aircraft for discrete points along the flight path. This data, along with corresponding altitude information, was incorporated into the AIMS PPM to simulate aircraft flights.

[1]Bulawka, A., Stover, S., *Evaluation of a Model for Synthesizing Aircraft Antenna Patterns,* ECAC-PR-75-064, ECAC, Annapolis, MD, November 1975.

The AIMS PPM is a computerized analysis model capable of evaluating the operation of all air traffic control and military identification modes. Given antenna pattern information, the AIMS PPM can be used to assess the effects that aircraft antenna patterns have on the performance of ATCRBS. This capability utilizes actual measured or synthesized patterns of antennas mounted on an aircraft, thereby permitting specific aircraft to be analyzed.

The aircraft transponder/antenna systems evaluated in this analysis were those of the Cessna 150, Boeing 727, Boeing 747, and F-4H. In addition, each aircraft transponder/antenna system was evaluated assuming the antenna was omnidirectional. All the antenna patterns except the ones for the F-4H were derived from measured data. The antenna patterns for the F-4H were synthesized using the Ohio State University antenna synthesis computer program (Reference 1).

ATCRBS performance was evaluated with each transponder/antenna system interacting with one terminal (short-range interrogator) installation and one en route (long-range interrogator) installation.

Section 2

MATHEMATICAL MODELS

AIMS PERFORMANCE PREDICTIONS MODEL (PPM)

The AIMS PPM[3] is an analysis capability designed to evaluate the operation of all air traffic control and military identification modes used in the AIMS and ATCRBS. An interrogator environment derived from ECAC's IFF Master file and an aircraft deployment that may be synthesized by the user or obtained from actual PPI scope photographs are applied to the model used. Operating characteristics of deployed transponders are specified by the model user.

The AIMS model is designed to provide a detailed set of performance predictions including such factors as interrogation rates, sidelobe suppression rates, reply probability, and probabilities of target detection and code validation for a specific scanario. However, for the analysis described in this report, only the propagation and antenna subroutines of the AIM PPM were used. These subroutines calculate the received signal level at both the transponder and the interrogator receiver for each interrogator/transponder pair. Included in the calculation are the effects of the 3-dimension aircraft antenna pattern model, a 2-path propagation model, and the elevation pattern of the interrogator antenna. The specific values used for such parameters as transmitted power, receiver sensitivity, and sensitivity-time control curves are listed in Section 3.

---

[3]Sutton, S., Ehler, C. W., *AIMS Performance Prediction Model System Report,* ESD-TR-72-286, ECAC, Annapolis, MD, January 1973. (SECRET) (Review January 1993)

AIRCRAFT ANTENNA PATTERN MODEL

The AIMS PPM has a subroutine that uses antenna pattern information to account for the imperfect coverage of actual aircraft antenna systems.[4] Based on aircraft location and attitude (heading, pitch, and roll angles), as specified by the user, the model determines the aspect angles (elevation and azimuth) of each interrogator with respect to the aircraft. These elevation and azimuth angles are used to determine which sector of the aircraft antenna pattern is "aimed" at each interrogator.

The method of locating each interrogator with respect to the aircraft is based on a spherical earth approximation. Elevation and azimuth angles (ϕ and σ) are initially computed assuming that the aircraft is flying straight and level and heading due North. Referenced to a rectilinear coordinate system centered at the aircraft, the line of position to a particular interrogator is represented by a unit vector, having the coordinates X_1, Y_1, Z_1, originating at the aircraft and pointing toward the interrogator (Figure 1). After these calculations have been made, the model takes into account aircraft heading, pitch, and roll through three successive rotations of the coordinate axis (Figure 2). The resultant unit vector (X_4, Y_4, Z_4), which can be defined by elevation and azimuth angles (ϕ, σ), determines which sector of the antenna pattern is to be used with each interrogator/transponder couplet.

[4]Gettier, C. A., *Performance of the Diversity Transponder System in an AIMS Environment*, ESD-TR-73-015, ECAC, Annapolis, MD, June 1973 (SECRET).

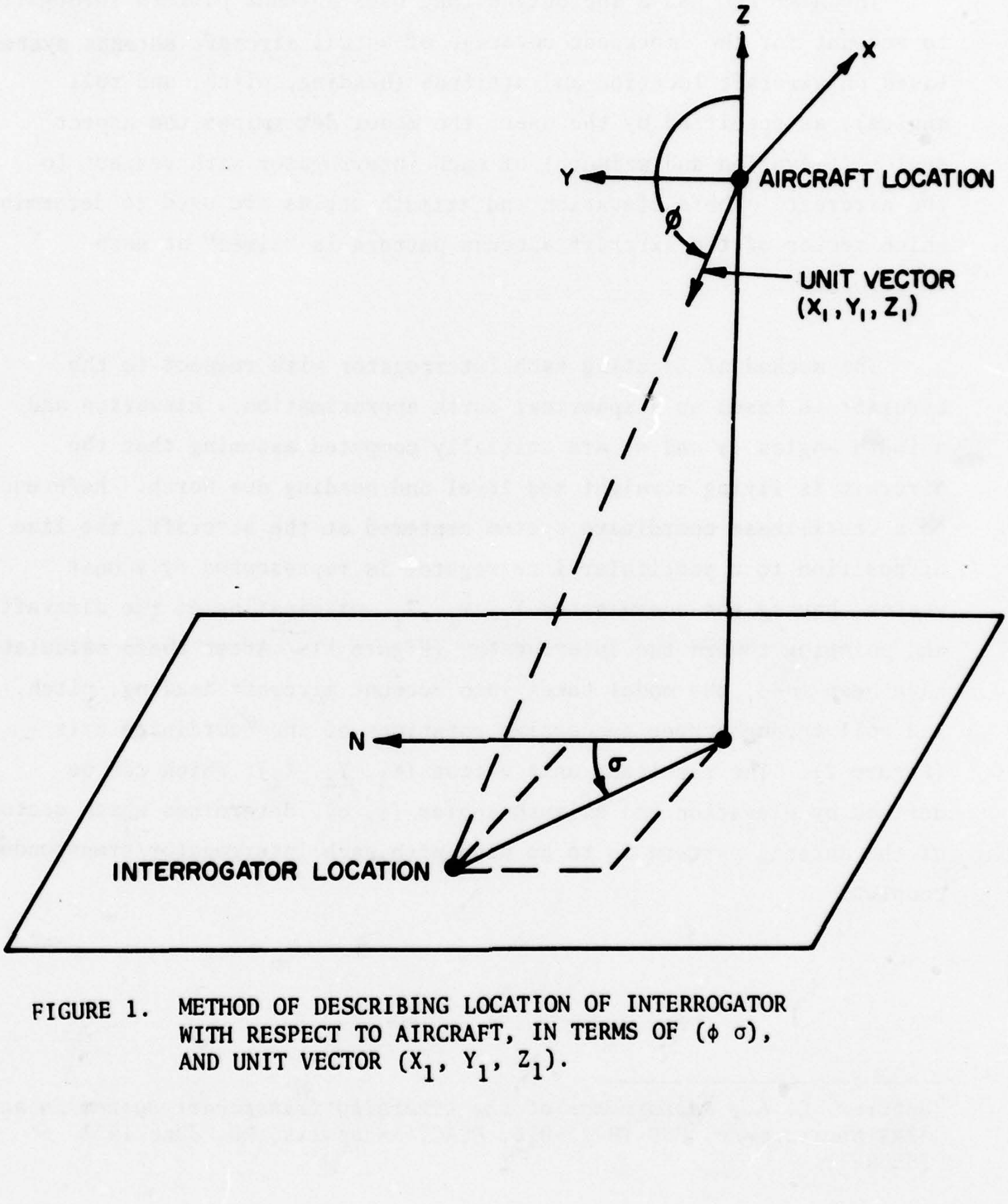
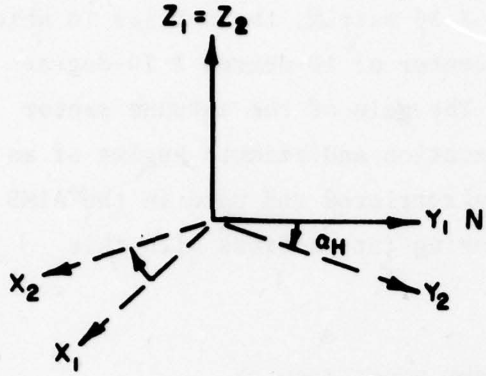


FIGURE 1. METHOD OF DESCRIBING LOCATION OF INTERROGATOR WITH RESPECT TO AIRCRAFT, IN TERMS OF (ϕ σ), AND UNIT VECTOR (X_1, Y_1, Z_1).

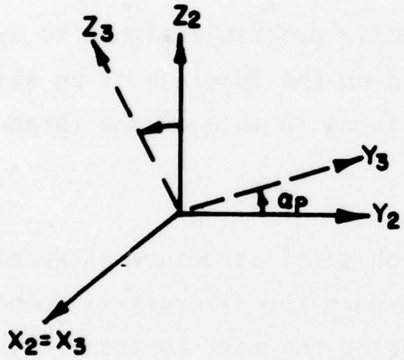


HEADING (YAW) PLANE ROTATION

$X_2 = X_1 \text{ COS } \alpha_H - Y_1 \text{ SIN } \alpha_H$

$Y_2 = X_1 \text{ SIN } \alpha_H + Y_1 \text{ COS } \alpha_H$

$Z_2 = Z_1$

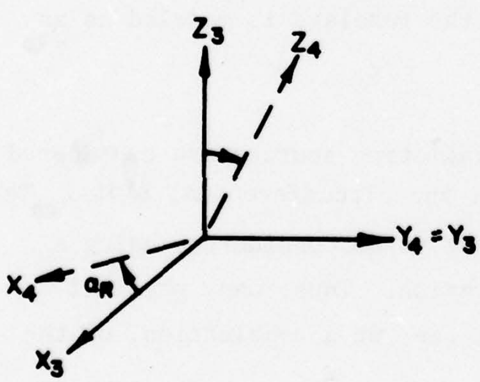


PITCH PLANE ROTATION

$X_3 = X_2$

$Y_3 = Y_2 \text{ COS } \alpha_P + Z_2 \text{ SIN } \alpha_P$

$Z_3 = -Y_2 \text{ SIN } \alpha_P + Z_2 \text{ COS } \alpha_P$



ROLL PLANE ROTATION

$X_4 = X_3 \text{ COS } \alpha_R + Z_3 \text{ SIN } \alpha_R$

$Y_4 = Y_3$

$Z_4 = -X_3 \text{ SIN } \alpha_R + Z_3 \text{ COS } \alpha_R$

FIGURE 2. METHOD OF DETERMINING INTERROGATOR ASPECT ANGLE WITH RESPECT TO HEADING, PITCH, AND ROLL ANGLES OF THE AIRCRAFT.

The antenna pattern, which is stored in a computer-accessible data file, is represented by an 18 X 36 matrix, the entries in which are the gains associated with the center of 10-degree X 10-degree sectors of the spherical pattern. The gain of the antenna sector corresponding to the calculated elevation and azimuth angles of an interrogator-transponder couplet is retrieved and used in the AIMS PPM as the aircraft antenna gain during interactions with this particular interrogator.

OHIO STATE UNIVERSITY ANTENNA PATTERN MODEL (OSUAP)

OSUAP (see Reference 1) is a computer program designed to synthesize radiation patterns for antennas mounted on the fuselage of an aircraft. The model is capable of generating patterns in each of the three principle planes of the aircraft.

OSUAP's capability to define the physical structure of an aircraft has certain limitations. The model assumes the aircraft is composed of flat plates and a cylinder, these being the most important contributors to the antenna pattern development. The engines and vertical stabilizer are omitted from consideration and the fuselage is modeled as an infinitely long cylinder.

Three types of infinitesimal radiating sources are considered by the model: monopole, and both axial and circumferential slots. The model allows for an arbitrary antenna to be considered, using a method of numerical aperture integration. Thus, many physical antennas can be approximated by any one, or a combination, of the three basic types.

An antenna pattern is a mathematical representation of the electric field strength surrounding a radiating source. The electric field vector ($\overline{E}$) in space may be represented in terms of two of its three orthogonal components, $\overline{E} = \overline{E}_{\phi} + \overline{E}_{\theta}$. The model computes the radiation pattern of the antenna in terms of these two components. For aircraft-mounted antennas, the aircraft structure can have a pronounced effect on the shape of the pattern of an otherwise omni-directional antenna. The protruding surfaces of the aircraft reflect and diffract the E vectors. The surface waves from a source mounted on an infinitely long cylinder propagate around the cylinder in helical paths, which in turn diffract energy tangentially. This diffracted energy that leaves the cylindrical surface is either reflected or further diffracted when it impinges on a wing. The model computes the total field by summing the directly radiated field and the scattered fields from the wings, using the superposition principle. A detailed mathematical description of the model's development was written by W. D. Burnside of Ohio State University.[5]

OSUAP antenna patterns are generated with respect to three orientations: roll plane; elevation plane (pitch); and azimuth plane (yaw). The elevation plane and azimuth plane configurations are obtained by shifting the roll plane orthogonally so that, in generating the antenna patterns, the aircraft is hypothetically rotated about its roll, pitch, or yaw axis, as appropriate.

[5]Burnside, W. D., "Analysis of On-Aircraft Antenna Patterns," Ohio State University, August 1972.

SECTION 3

ANALYSIS

MODEL INPUTS

Flight Plan

One flight plan was prepared for this analysis. From the flight plan, simulated flights were constructed for the Cessna 150, Boeing 727, Boeing 747, and F-4H aircraft as they were paced through various maneuvers. The flights were simulated by defining heading, roll, and pitch angles for each aircraft at a number of discrete points along the flight path and then entering them into the AIMS PPM simulations.

The flight route used by all aircraft in shown in Figure 3. The route was subdivided into 22 segments corresponding to the various maneuvers that were made by the aircraft. TABLES 1 and 2 correlate the aircraft positions (discrete points along the flight path) with each segment.

The flight plan called for an aircraft to depart from New York's La Guardia airport at a heading of 180° with respect to True North; climb to 10,000 feet while making two successive 90° left turns to a heading of 0° toward White Plains, New York. Approximately 27 miles north of La Guardia, the aircraft made a 120° left turn, establishing a new heading of 240° toward the Solberg VORTAC. A 138° right turn was initiated approximately two miles from Solberg, to a new heading of 18° toward the Albany airport.

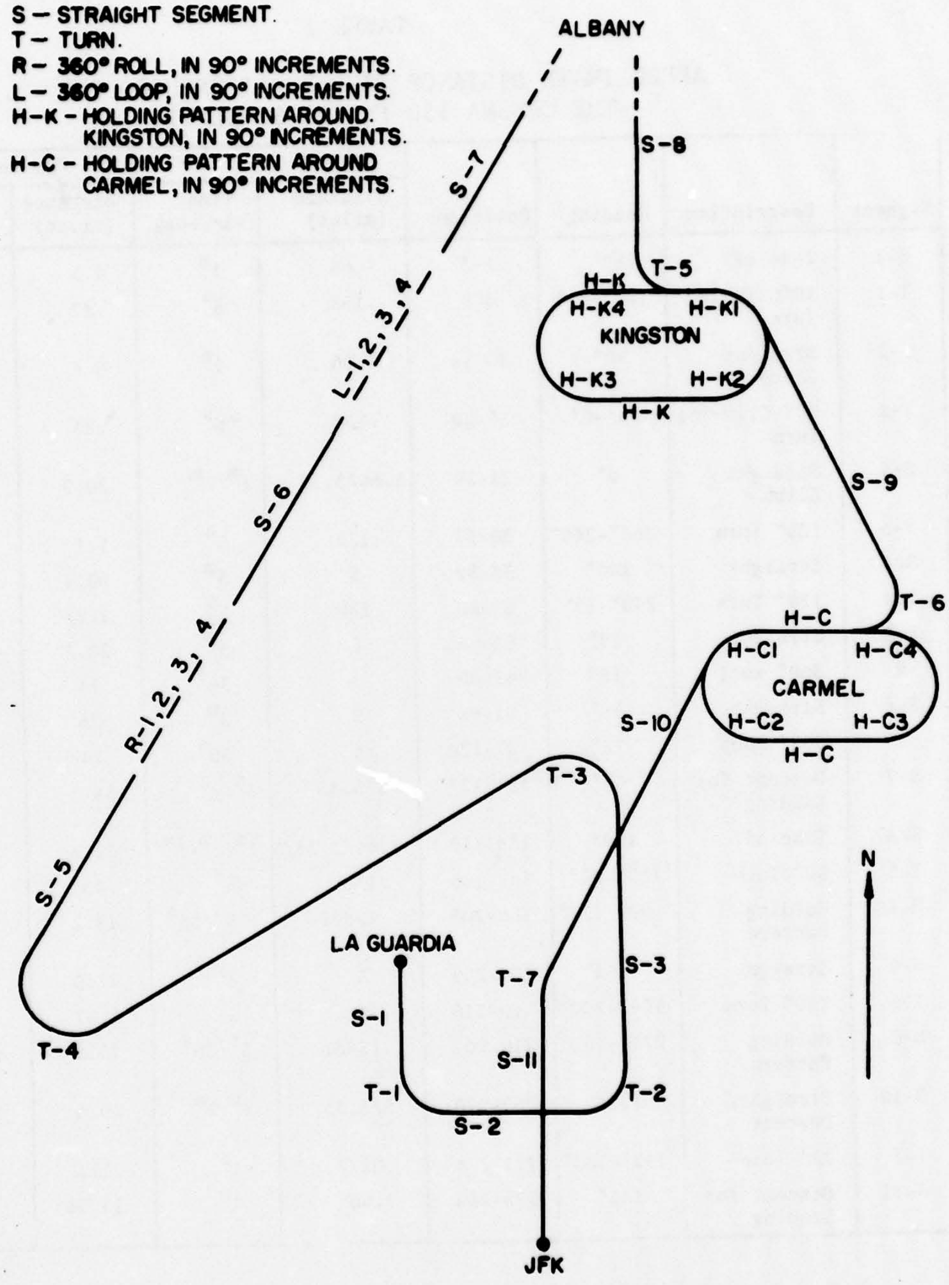


FIGURE 3. FLIGHT PATH USED IN SIMULATIONS.

TABLE 1

APPROXIMATE DISTANCE/TIME RELATIONSHIPS FOR THE CESSNA 150 FLIGHT SIMULATION

Segment	Description	Heading	Positions	Between Positions: Distance (miles)	Between Positions: Time (min,sec)	Per Segment: Distance (miles)	Per Segment: Time (min,sec)
S-1	Take-off	180°	1-3	1.66	1^m	4.5	2^m42^s
T-1	90°Climbing Turn	180°-90°	4-9	.138	5^s	.83	30^s
S-2	Straight Climb	90°	10-14	1.66	1^m	6.4	3^m52^s
T-2	90° Climbing Turn	90°-0°	15-20	.138	5^s	.83	30^s
S-3	Straight Climb	0°	21-29	1.66/3.33	$1^m/2^m$	20.9	12^m36^s
T-3	120° Turn	360°-240°	30-37	.138	5^s	1.1	40^s
S-4	Straight	240°	38-50	5	3^m	60.4	36^m12^s
T-4	138° Turn	240°-18°	51-60	.138	5^s	1.27	46^s
S-5	Straight	18°	61-66	5	3^m	28.7	17^m12^s
R	360° roll	18°	67-90	1	36^s	24	14^m24^s
S-6	Straight	18°	91-96	5	3^m	26	15^m36^s
L	360° Loop	18°	97-120	1	36^s	24	14^m24^s
S-7	Descent for Landing	18°	121-137	5/3.33	$3^m/2^m$	54.3	32^m36^s
S-8	Take-off	180°	138-159	1.66/3.33/5	$1^m/2^m/3^m$	72.3	43^m22^s
T-5	90° Turn	180°-90°	160-165	.138	5^s	.83	30^s
H-K	Holding Pattern	90°-154°	166-203	.138/1	$5^s/36^s$	12.2	$7^m/18^s$
S-9	Straight	154°	204-209	5	3^m	27.5	16^m29^s
T-6	116° Turn	154°-270°	210-218	.138	5^s	1.07	38^s
H-C	Holding Pattern	270°-192°	219-261	.138/1	$5^s/36^s$	16.6	9^m59^s
S-10	Straight/ Descent	192°	262-270	5/3.33	$3^m/2^m$	29.6	17^m45^s
T-7	12° Turn	192°-180°	271-274	.0277	1^s	.111	4^s
S-11	Descent for Landing	180°	275-283	1.66	1^m	13.33	8^m

TABLE 2

APPROXIMATE DISTANCE/TIME RELATIONSHIPS FOR THE FLIGHT SIMULATION OF THE BOEING 727, BOEING 747 AND F-4H AIRCRAFT

				Between Positions		Per Segment	
Segment	Description	Heading	Positions	Distance (miles)	Time (min,sec)	Distance (miles)	Time (min,sec)
S-1	Take-off	180°	1-3	1.33	18.5^s	2.85	40^s
T-1	90° Climbing Turn	180°-90°	4-9	.36	5^s	2.2	30^s
S-2	Straight Climb	90°	10-14	1.66	23^s	3.8	52^s
T-2	90° Climbing Turn	90°-0°	15-20	.36	5^s	2.2	30^s
S-3	Straight Climb	0°	21-29	1.66/3.33[a]	$23^s/46^s$	20.9	4^m50^s
T-3	120° Turn	360°-240°	30-46	.36	5^s	6.45	1^m29^s
S-4	Straight	240°	47-58	5	1^m9^s	55.1	12^m43^s
T-4	138° Turn	240°-18°	59-68	.36	5^s	3.45	47^s
S-5	Straight	18°	69-74	5	1^m9^s	26.5	6^m7^s
R	360° Roll	18°	75-98	1	13.8^s	24	5^m32^s
S-6	Straight	18°	99-104	5	1^m9^s	26	6^m
L	360° Loop	18°	105-128	1	13.8^s	24	5^m32^s
S-7	Descent for Landing	18°	129-145	5/3.33/1.66	$6^m9^s/46^s$	54	12^m30^s
S-8	Take-off	180°	146-167	1.66/3.33/5	$23^s/46^s$	71.8	16^m35^s
T-5	90° Turn	180°-90°	168-173	.36	5^s	2.2	30^s
H-K	Holding Pattern	90°-154°	174-211	.36/1	$5^s/13.8^s$	18.2	4^m12^s
S-9	Straight	154°	212-217	5	1^m9^s	26	6^m2^s
T-6	116° Turn	154°-270°	218-226	.36	5^s	2.8	38^s
H-C	Holding Pattern	270°-192°	227-269	.36/1	$5^s/13.8^s$	21.9	5^m3^s
S-10	Straight/ Descent	192°	270-278	5/3.33	$1^m9^s/46^s$	29.6	6^m49^s
T-7	12° Turn	192°-180°	279-282	.07	1^s	.3	4^s
S-11	Descent for Landing	180°	283-291	1.66	23^s	13.3	3^m4^s

The aircraft remained on this course for approximately 157 miles, landing at the airport in Albany, New York. For the return flight, the aircraft departed from Albany airport on a heading of 180° with respect to True North and climbed to 10,000 feet while heading toward the Kingston VORTAC. Approximately 72 miles south of Albany, the aircraft made a 90° left turn and entered a holding pattern, circling the Kingston VORTAC. A heading of 154° toward the Carmel VORTAC was established when the aircraft left the holding pattern around Kingston. As the aircraft approached the Carmel VORTAC, it made a 116° right turn into a holding pattern around the Carmel VORTAC. A new heading of 192° toward JFK International Airport was taken upon leaving the holding pattern around Carmel. Approximately 16 miles from JFK International Airport, a 12° left turn was made to a new heading of 180° as the aircraft approached JFK International Airport to land.

Cessna 150 Flight Path

In the case of the Cessna 150, the aircraft was assumed to be traveling at a constant air speed of 100 mph; making turns at a standard 3°-per-second turn rate while banking at a 15° angle; climbing 500 feet per minute at a 15° pitch angle during take-offs; and decending 500 feet per minute at a 15° pitch angle during landings. A total of 283 positions with associated heading, roll, and pitch angles defined, were used to describe the Cessna 150 flights as the aircraft traversed the flight route (see TABLE A-1 in APPENDIX A). Increments of 500 feet of altitude during take-offs and landings, 15° of heading when maneuvering through a turn, and 5 miles of distance when maintaining a steady course, were the criteria used for selecting the 283 locations. In addition, during the flight segment between the Solberg VORTAC and Albany airport , the Cessna 150 was paced through a 360° roll and a vertical loop, each maneuver being described in 24 successive 15° increments. The holding patterns at Kingston and Carmel required 180° turns to be made with a 6.3-mile diameter and a 4-mile separation between turns.

Boeing 727, Boeing 747, and F-4H Flight Paths

Another simulated flight path was constructed for use with the Boeing 727, Boeing 747, and F-4H flights. All three aircraft were assumed to be traveling at a constant airspeed of 260 mph making turns at the standard 3°-per-second turn rate while banking at a 15° angle; climbing 2,500 feet per minute at a 15° pitch angle during take-offs; and decending 2,500 feet per minute at a 10° pitch angle during landings. A total of 291 positions, with associated heading, roll, and pitch angles defined, were used to describe the flights as each aircraft traversed the flight route (see TABLE A-1, in APPENDIX A). The locations, when possible, were selected to coincide with the ones used for the Cessna 150 flight. The turns were longer than those of the Cessna 150 due to increased airspeed. The Boeing 727, Boeing 747, and F-4H were also paced through 360°-roll and loop manuevers during the flight segment between the Solberg VORTAC and Albany airport. The 360° roll and loop are never expected to be executed by the Boeing 727 and Boeing 747 during an actual flight, but were simulated in this analysis in order to create a cross-section of possible aircraft orientations for evaluating ATCRBS transponder/antenna system performance.

Two installations at JFK International Airport, a long-range interrogator and a terminal interrogator, were selected as the interrogators of interest. An ATCBI-4 interrogator was used at the terminal installation and an ATCBI-3E interrogator was used at the long-range installation. TABLE 3 lists the operating characteristics for each of the interrogators.

TABLE 3

PERTINENT INTERROGATOR CHARACTERISTICS

CHARACTERISTIC	Long Range ATCBI-3E	Terminal ATCBI-4
Power (kW)	0.6	0.1
Receiver Sensitivity (dBm)	-87.5	-84
Antenna Height (ft)[a]	120	45
Antenna Mainbeam Gain (dBi)	28	21
Maximum Depth of Sensitivity-Time Control Curve (dB)	55	40

[a]Includes site elevation

TRANSPONDER CHARACTERISTICS

Three basic groups of transponders are used in the ATCRBS. Each group is related to one of the following types of aircraft and their function: general aviation, air carrier, and military. Included in each group are a number of transponders with similar operating characteristics. In the analysis, three representative types of transponders were utilized during the AIMS PPM simulations: air carrier transponders were assigned to the Boeing 727 and Boeing 747 aircraft, a military transponder was assigned to the F-4H, and general aviation transponders were assigned to the Cessna 150.

ANTENNA PATTERNS

Measured antenna patterns were used in the analysis for the Boeing 727, Boeing 747, and Cessna 150 aircraft. The measurements were made at Lincoln Laboratory at their Bedford antenna test range and by the Boeing Commercial Airplane Company.[6] Since antenna patterns cannot reasonably be made on full size aircraft, scale model aircraft were used. The models were scaled 1/20th to 1/40th the size of the actual aircraft, requiring that the test frequencies be 20 times to 40 times that of the L-band frequencies employed by the antenna.

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[6]Schlieckert, G., *An Analysis of Aircraft L-Band Beacon Antenna Patterns*, FAA-RD-74-144, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Mass, December 16, 1974.

Synthesized antenna patterns generated by OSUAP were used in the analysis for the F-4H aircraft. ATCRBS transponder antennas, small-diameter angular slots on the fuselage, were modeled as monopole antennas in OSUAP since they essentially have the same radiation pattern as a monopole that is mounted on an ideal ground plane.

The measured and synthesized antenna patterns for each aircraft roll, elevation, and azimuth planes are shown in APPENDIX B. The spherical radiation pattern of each aircraft transponder antenna was used by the AIMS PPM while evaluating the performance of each Aircraft ATCRBS transponder during a simulated flight.

ANTENNA COVERAGE

Signal levels received by the ATCBI-3E and ATCBI-4 interrogators from each of the aircraft as they traversed the flight route were calculated by the AIMS PPM. The results yielded by these simulations were then compared to signal levels that would be received if the aircraft had ideal, 0-dBi omni-directional antenna coverage. Figures 4 through 11 show the signal power received by the individual interrogators from the Cessna 150, F-4H, Boeing 727, and Boeing 747 aircraft transponders as they traversed the flight route. The signal levels that would be received by the interrogators from an aircraft with ideal omni-directional antenna coverage are also included in Figures 4 through 11 for comparision. The location of the aircraft with respect to the various straight portions, maneuvers, and turns of the flight path can be found by referencing TABLES 1 and 2 and Figure 3. Gaps in the coverage were particularly apparent as the aircraft approached Albany to land, and again as the aircraft were taking off from Albany. This is because, at this point, they were beyond the line-of-sight of the interrogators located at JFK International Airpor

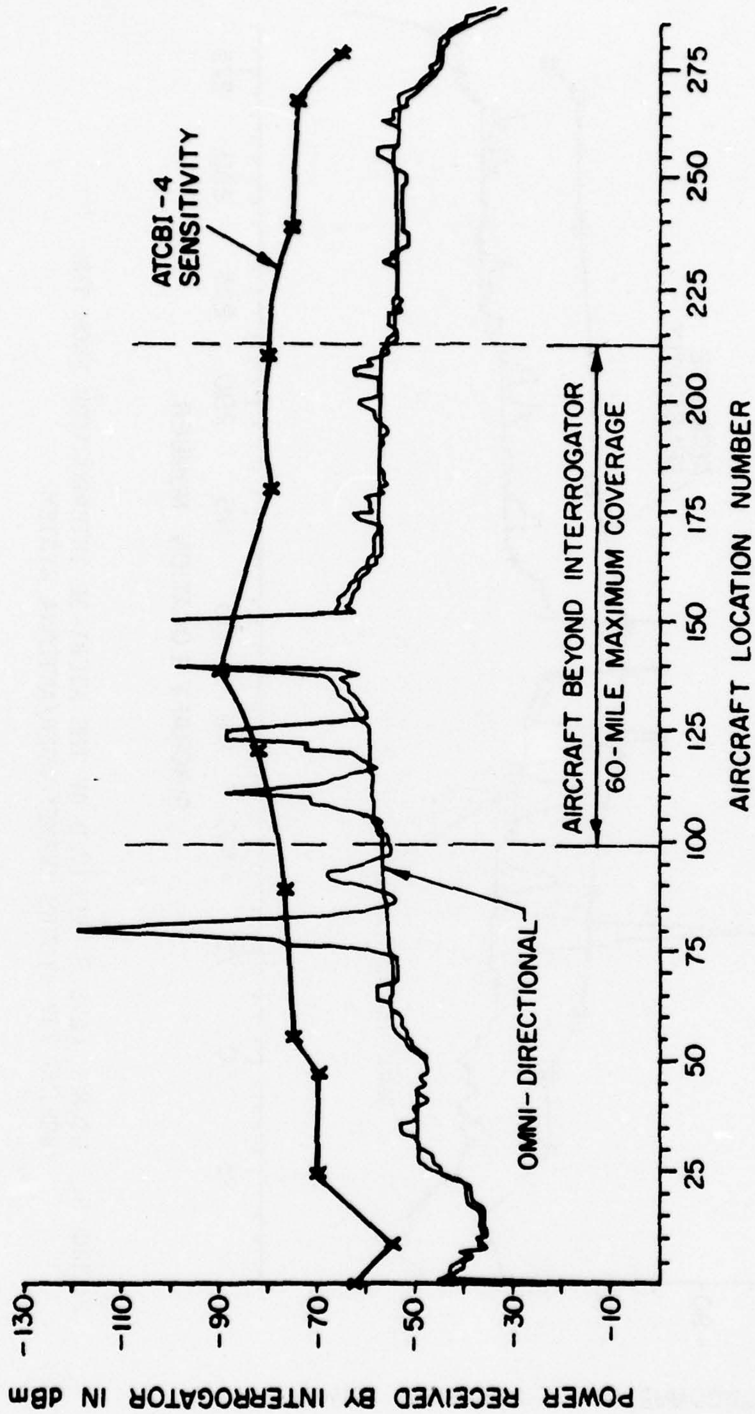

FIGURE 4. SIGNAL LEVELS RECEIVED BY THE ATCBI-4 INTERROGATOR FROM THE BOEING 727 ATCRBS TRANSPONDER/ANTENNA SYSTEM.

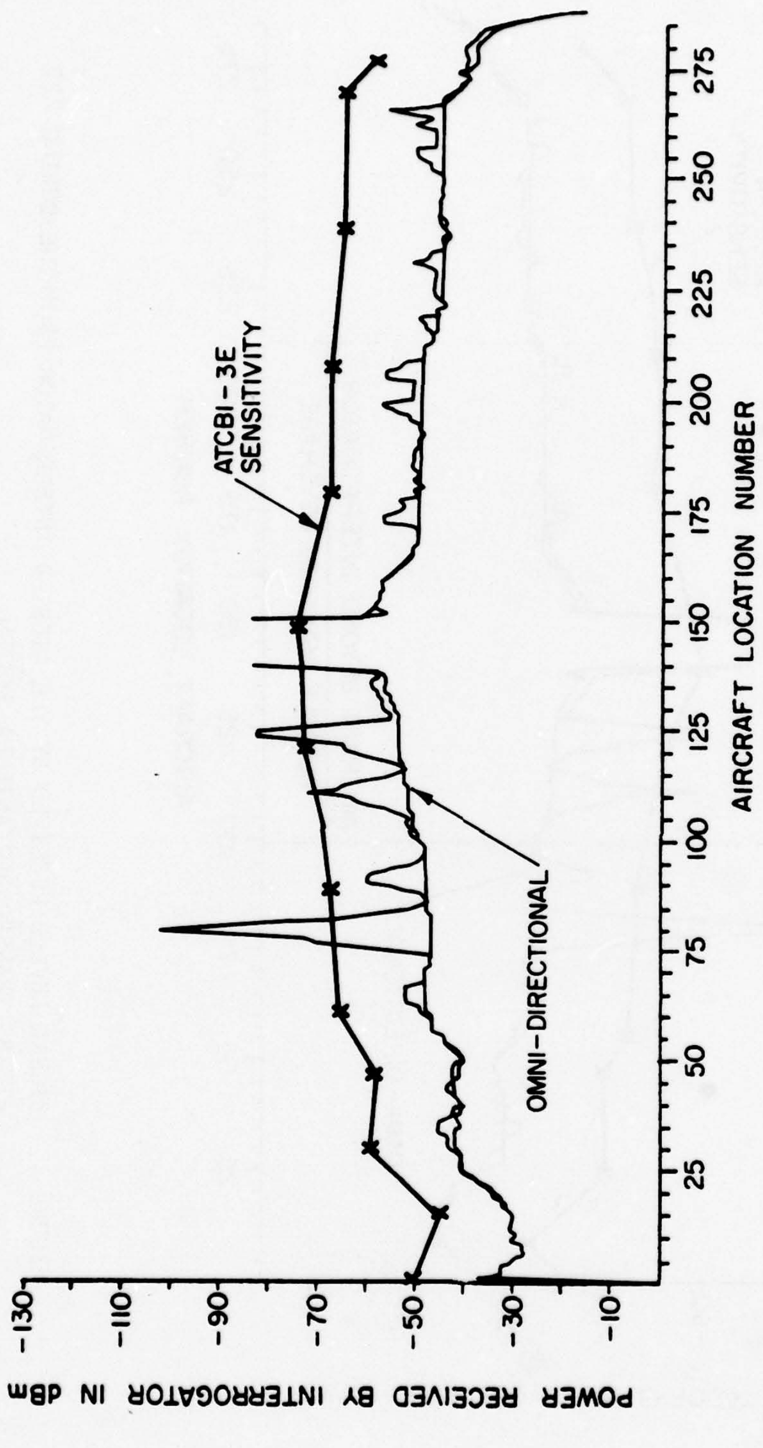

FIGURE 5. SIGNAL LEVELS RECEIVED BY THE ATCBI-3E INTERROGATOR FROM THE BOEING 727 ATCRBS TRANSPONDER/ANTENNA SYSTEM.

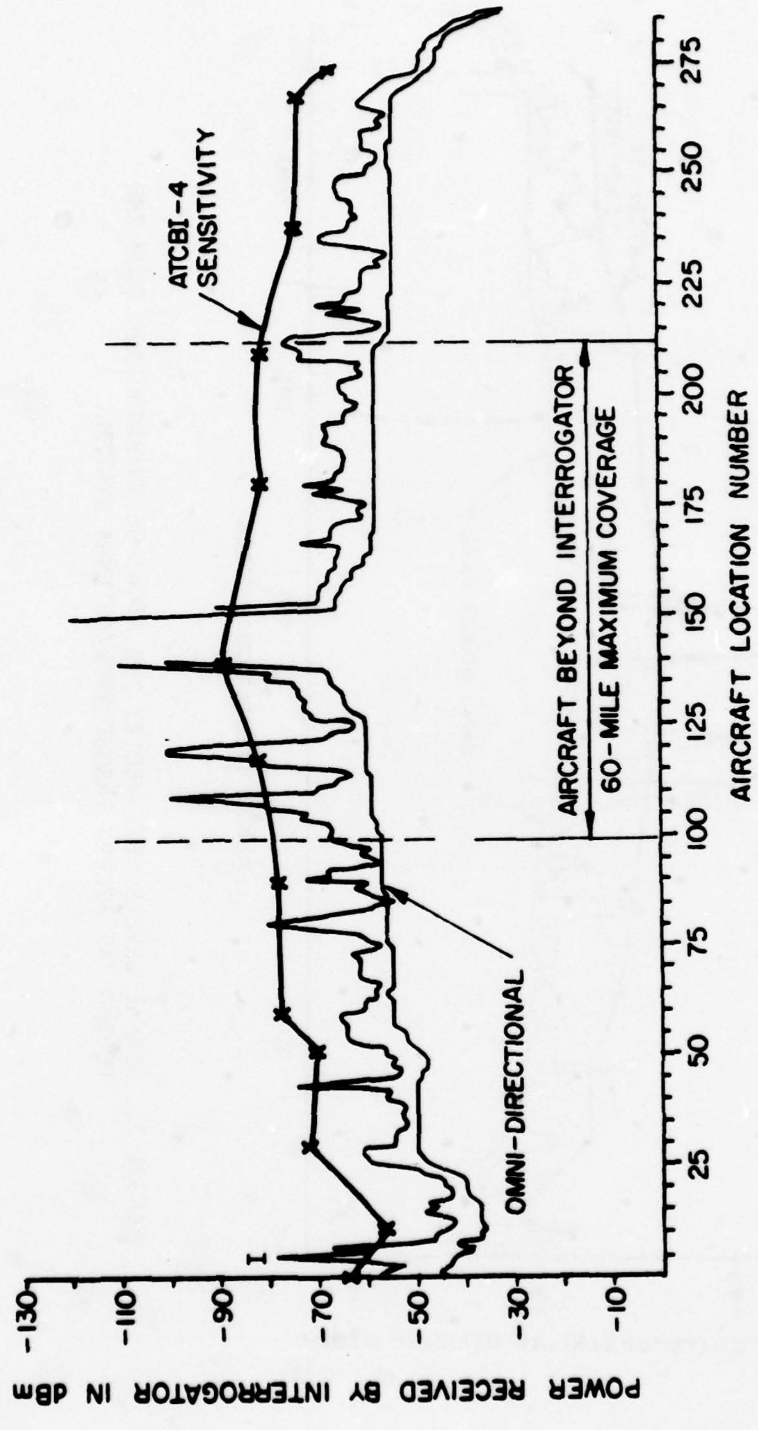

FIGURE 6. SIGNAL LEVELS RECEIVED BY THE ATCBI-4 INTERROGATOR FROM THE BOEING 747 ATCRBS TRANSPONDER/ANTENNA SYSTEM.

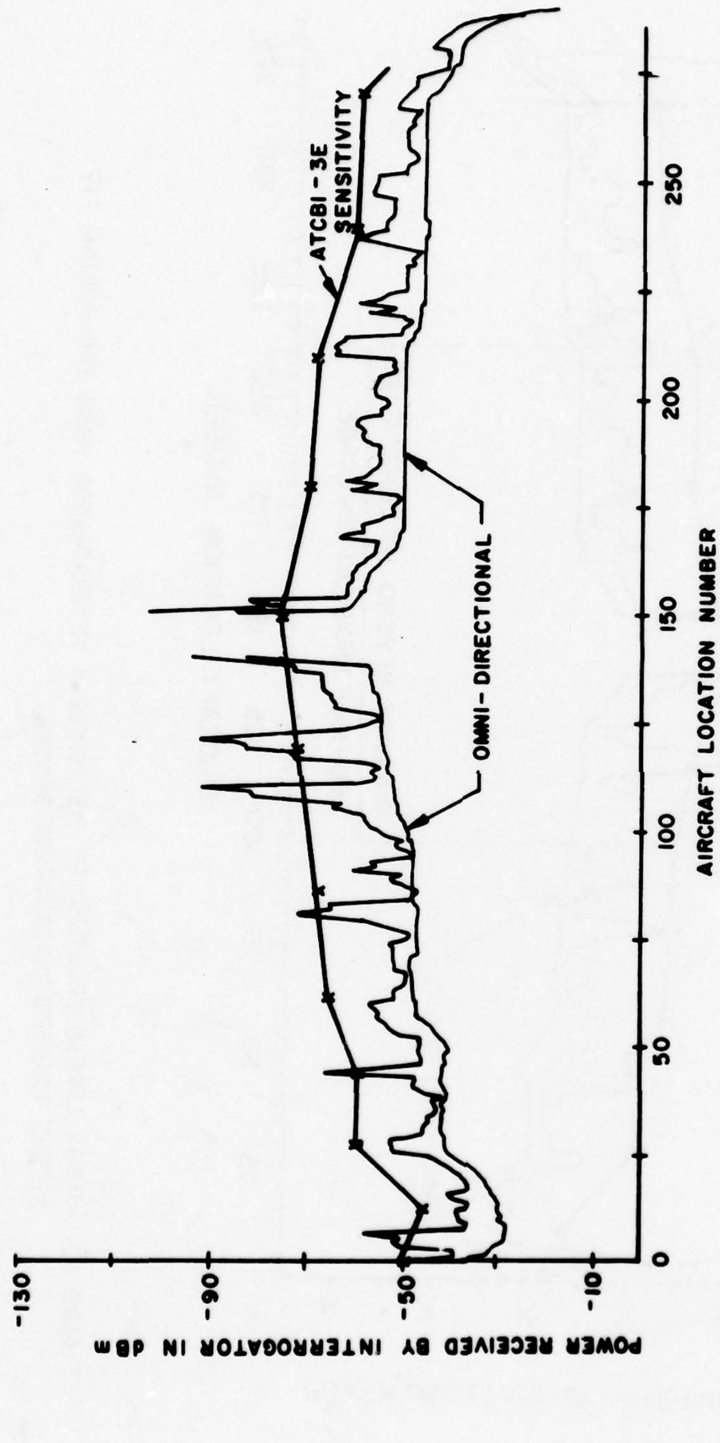

FIGURE 7. SIGNAL LEVELS RECEIVED BY THE ATCBI-3E INTERROGATOR FROM THE BOEING 747 ATCRBS TRANSPONDER/ANTENNA SYSTEM.

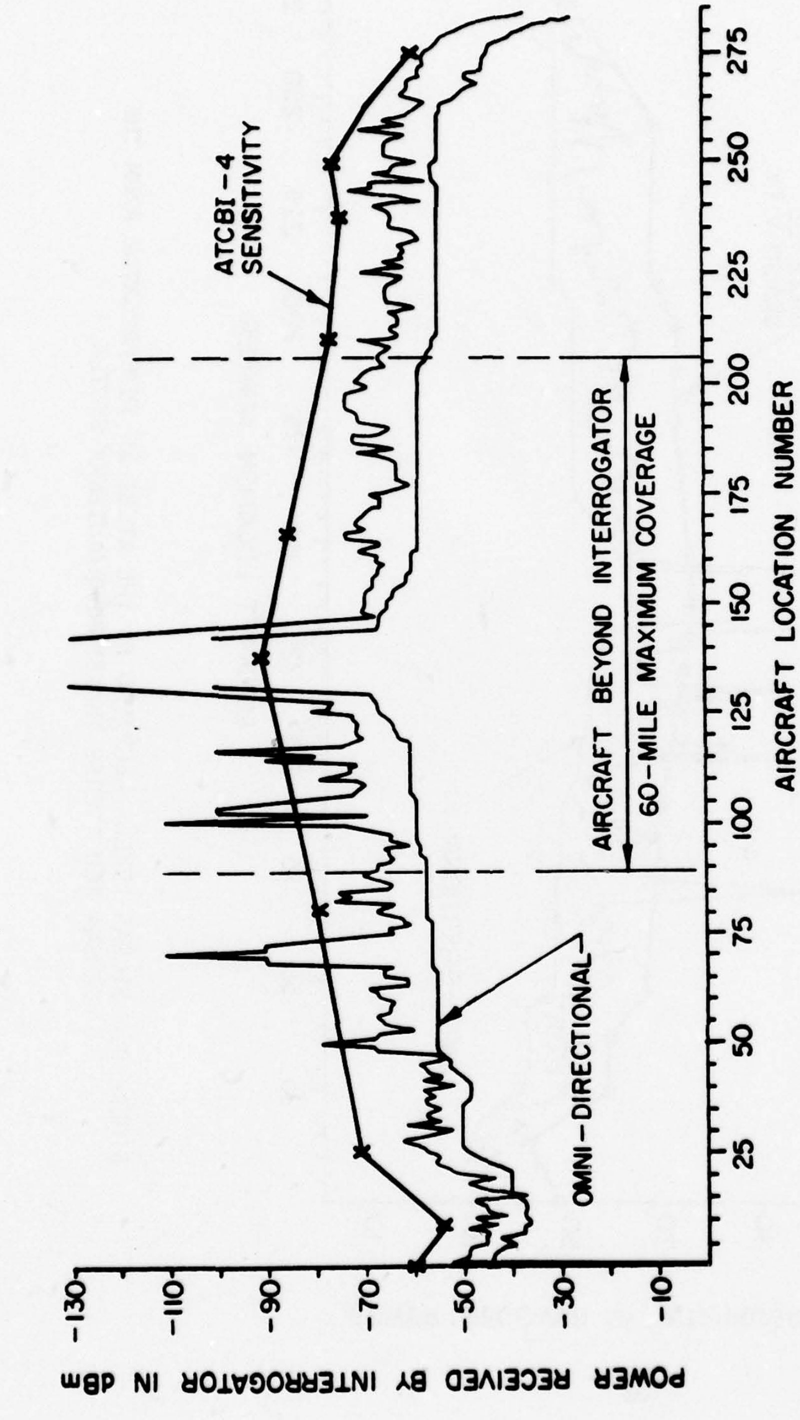

FIGURE 8. SIGNAL LEVELS RECEIVED BY THE ATCBI-4 INTERROGATOR FROM THE CESSNA 150 ATCRBS TRANSPONDER/ANTENNA SYSTEM.

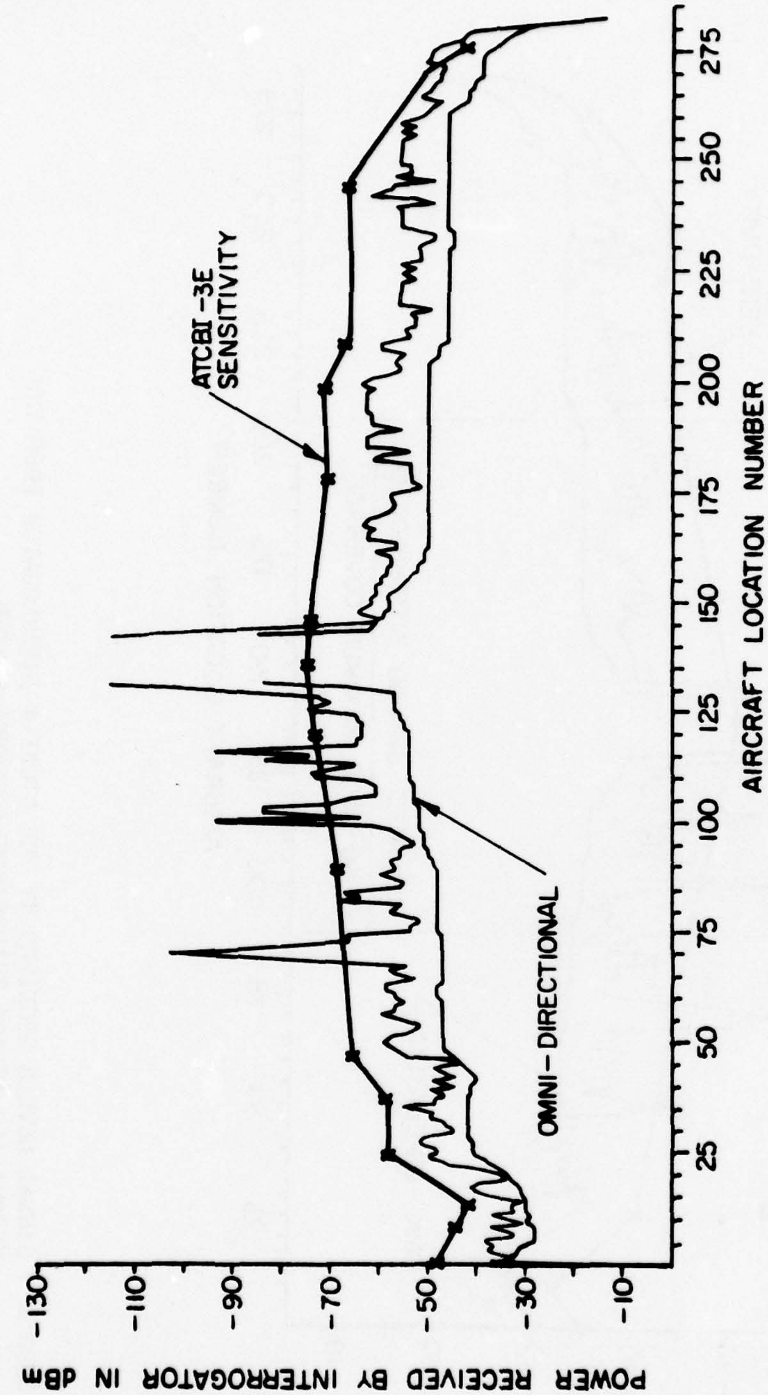

FIGURE 9. SIGNAL LEVELS RECEIVED BY THE ATCBI-3E INTERROGATOR FROM THE CESSNA 150 ATCRBS TRANSPONDER/ANTENNA SYSTEM.

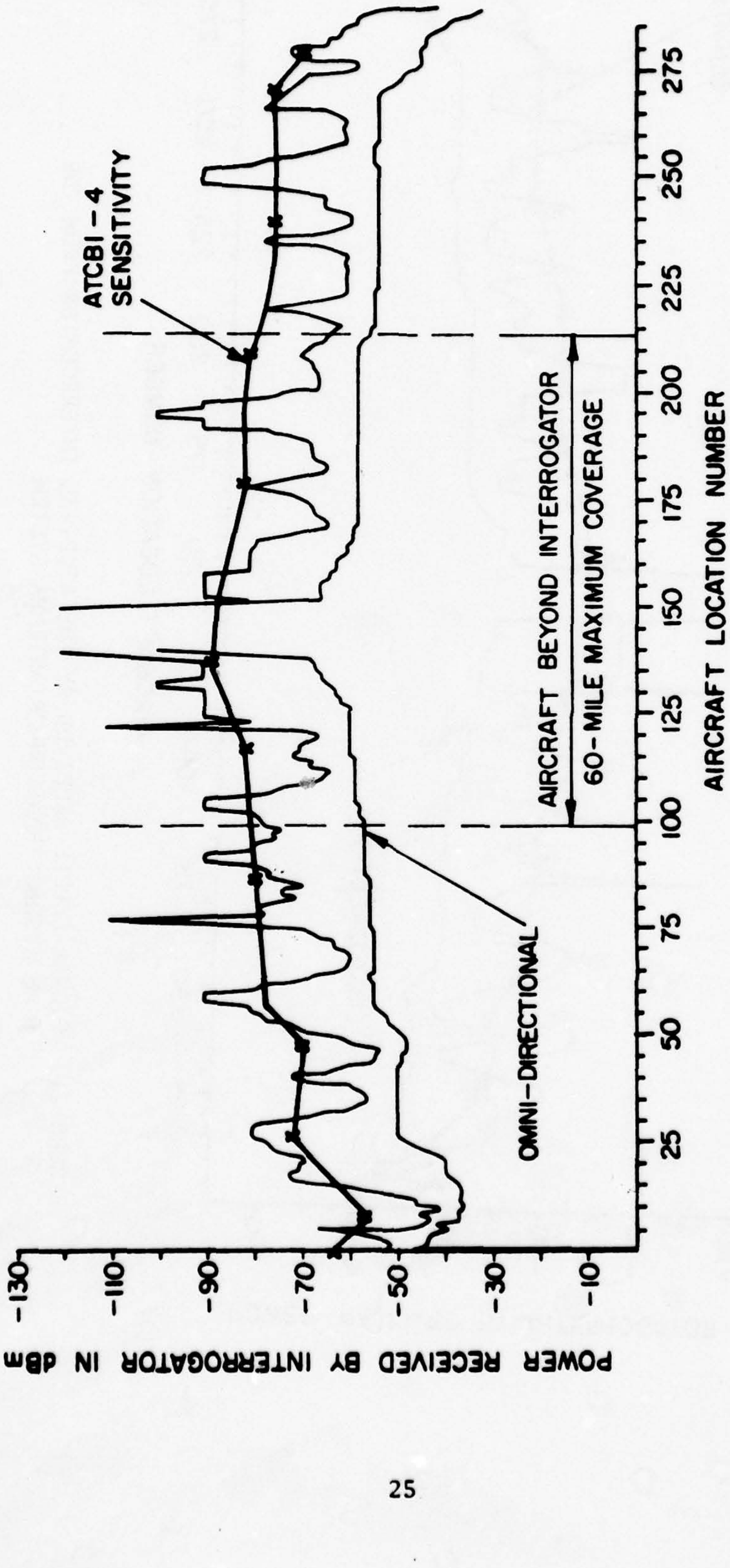

FIGURE 10. SIGNAL LEVELS RECEIVED BY THE ATCBI-4 INTERROGATOR FROM THE F-4H TRANSPONDER/ANTENNA SYSTEM.

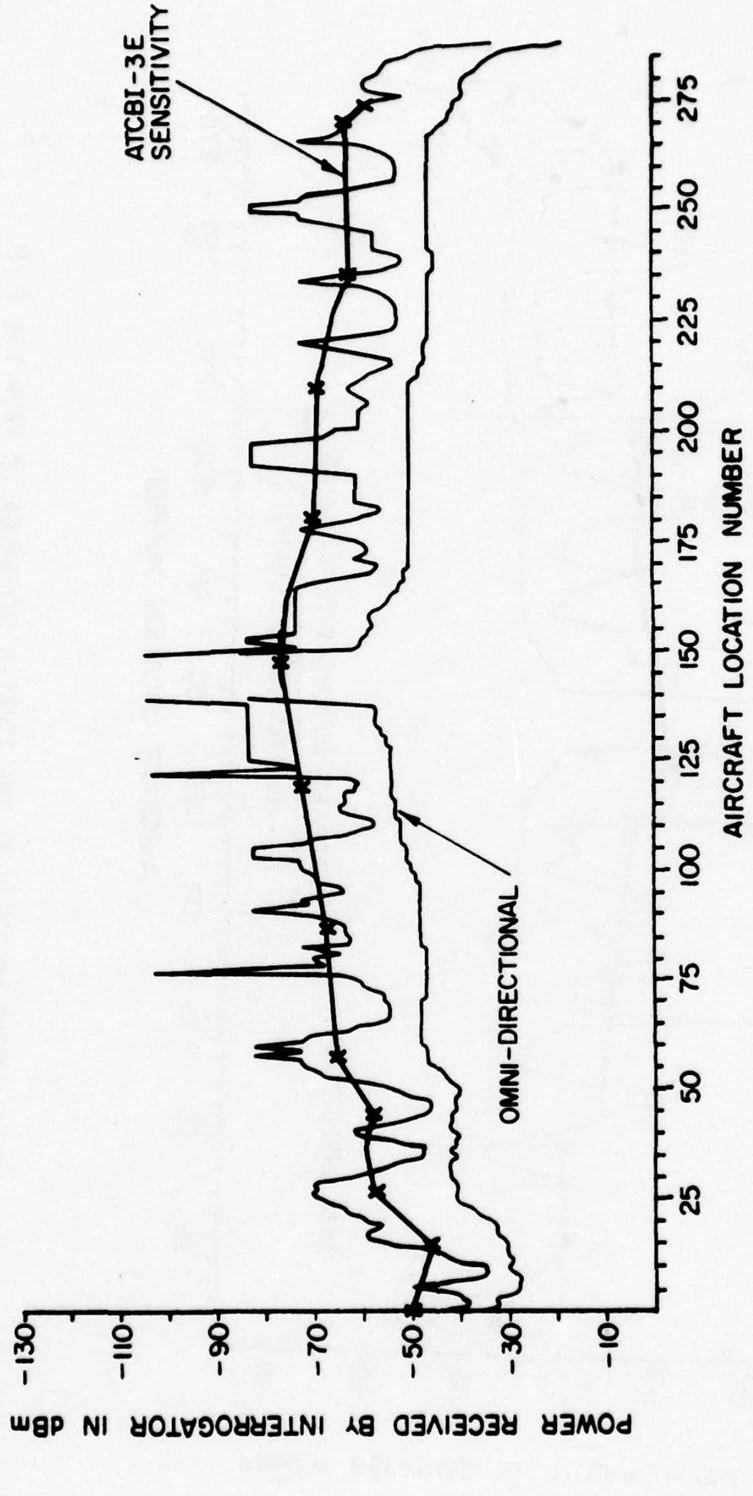

FIGURE 11. SIGNAL LEVELS RECEIVED BY THE ATCBI-3E INTERROGATOR FROM THE F-4H ATCRBS TRANSPONDER/ANTENNA SYSTEM.

SUMMARY

Figures 4 and 5 show the power levels received from the Boeing 727 ATCRBS transponder/antenna system by the ATCBI-4 (terminal) interrogator and the ATCBI-3E (en route) interrogator. The figures show that, during most of the simulated flight, the actual antenna coverage is very similar to the coverage that would be obtained if the aircraft had an ideal omni-directional antenna. The differences in the power levels received by the interrogator from the actual and ideal omni-antennas were very small for most of the aircraft locations. Signal reductions greater than 10 dB occurred only during the unusual roll and loop maneuvers, with the largest reduction (55 dB) occurring while the aircraft was in its roll pattern (-60° to -105°). The reply signals were attenuated below the sensitivity of the interrogator receiver only during a small portion of these maneuvers. During an actual flight, these maneuvers are not expected to occur.

Figures 6 and 7 show the power levels received from the Boeing 747 ATCRBS transponder/antenna system by the ATCBI-4 and the ATCBI-3E interrogators receivers. These figures demonstrate by comparison with Figures 4 and 5, that the coverage for the 747 is similar to that for the 727. The variation in the received signal level is slightly more irregular in the case of the 747, but one margin between the interrogator receiver sensitivity and the received signal level is sufficient to withstand the majority of the pattern nulls.

Figures 8 and 9 show the power levels received from the Cessna 150 general aviation transponder/antenna system at the ATCBI-4 interrogator and at the ATCBI-3E interrogator. These figures show that the received signal levels are no more irregular than for the Boeing 747. However, when large nulls in the Cessna 150 antenna pattern occur, they are generally deeper than those that occur for the Boeing 727. The result is that when losses in coverage occur for the Cessna 150, the losses persist for a longer period of time.

The received power levels from the F-4H transponder/antenna system at the ATCBI-4 and the ATCBI-3E are shown in Figures 10 and 11. The figures clearly demonstrate the frequent nulls that occur in the F-4H antenna pattern. The top-mounted antenna of the F-4H is shielded from the ground interrogator antennas off and on throughout the entire flight path. In addition, during some portions of the flight path where the reply signals from the F-4H are received above the interrogator receiver sensitivity, the margin between signal level and sensitivity is small.

TABLE 4 shows the percentage of time along the flight path that the transponder reply signals were received above the interrogator receiver sensitivity for each interrogator/transponder pair.

TABLE 4

PERCENTAGE OF FLIGHT PATH FOR WHICH TRANSPONDER REPLIES COULD BE RECEIVED ABOVE INTERROGATOR RECEIVER SENSITIVITY

AIRCRAFT	ATCBI-4 (Terminal)	ATCBI-3E (En Route)
Boeing 727	.99	.96
Boeing 747	.99	.96
Cessna 150	.98	.87
F-4H	.91	.64

SECTION 4

CONCLUSIONS

1. The performance of the top-mounted antenna system on the F-4H aircraft was unsatisfactory. Large variations in antenna gain (see Figures 10 and 11) resulted in periodic loss of signal at the ground interrogator.

2. The performance of the Cessna 150 transponder/antenna system, while significantly better than that for the F-4H aircraft (see Figures 8 and 9), resulted in occasional loss of coverage at the ground sites.

3. The transponder antenna coverage of the Boeing 727 and F-4H and the 747 configurations was significantly better than that for the Cessna 150. In most cases, the antenna coverage for these aircraft approached that of an ideal omni-directional antenna.

APPENDIX A

AIRCRAFT LOCATIONS DEFINING THE FLIGHT PATHS USED IN THE ANALYSIS

Each location is defined by latitude, longitude, altitude, and aircraft heading, pitch and roll. The headings are with reference to true north; a positive pitch occurs when the nose of the aircraft is pointed upward; a negative pitch occurs when the nose is pointed down. Viewing the aircraft from astern, a positive roll occurs when the wings of the aircraft rotate in a counter-clockwise direction, and a negative roll occurs when the wings of the aircraft rotate in a clockwise direction. TABLE A-1 is for the Cessna 150 aircraft. TABLE A-2 is for the Boeing 727, Boeing 747 and F-4H aircraft.

TABLE A-1

AIRCRAFT POSITIONS DEFINING THE FLIGHT PATH
FOR THE CESSNA 150
(Page 1 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
1	S-1	40 45 32N	73 51 59W	500	180	15	0
2	S-1	40 44 05N	73 51 59W	1,000	180	15	0
3	S-1	40 43 07N	73 51 59W	1,342	180	15	0
4	T-1	40 43 00N	73 51 58W	1,383	165	15	15
5	T-1	40 42 53N	73 51 54W	1,425	150	15	15
6	T-1	40 42 47N	73 51 48W	1,467	135	15	15
7	T-1	40 42 43N	73 51 41W	1,509	120	15	15
8	T-1	40 42 40N	73 51 32W	1,550	105	15	15
9	T-1	40 42 39N	73 51 23W	1,592	90	15	0
10	S-2	40 42 39N	73 49 51W	2,000	90	15	0
11	S-2	40 42 39N	73 47 58W	2,500	90	15	0
12	S-2	40 42 39N	73 46 05W	3,000	90	15	0
13	S-2	40 42 39N	73 44 12W	3,500	90	15	0
14	S-2	40 42 39N	73 44 06W	3,525	90	15	0
15	T-2	40 42 40N	73 43 57W	3,567	75	15	15
16	T-2	40 42 43N	73 43 48W	3,609	60	15	15
17	T-2	40 42 47N	73 43 41W	3,650	45	15	15
18	T-2	40 42 53N	73 43 35W	3,692	30	15	15
19	T-2	40 42 59N	73 43 31W	3,734	15	15	15
20	T-2	40 43 07N	73 43 30W	3,776	0	15	0
21	S-3	40 43 46N	73 43 30W	4,000	0	15	0
22	S-3	40 45 13N	73 43 30W	4,500	0	15	0
23	S-3	40 46 40N	73 43 30W	5,000	0	15	0
24	S-3	40 49 34N	73 43 30W	6,000	0	15	0
25	S-3	40 52 27N	73 43 30W	7,000	0	15	0
26	S-3	40 55 27N	73 43 30W	8,000	0	15	0
27	S-3	40 58 15N	73 43 30W	9,000	0	15	0
28	S-3	41 01 08N	73 43 30W	10,000	0	0	0
29	S-3	41 01 19N	73 43 30W	10,000	0	0	0
30	T-3	41 01 26N	73 43 31W	10,000	345	0	15
31	T-3	41 01 33N	73 43 35W	10,000	330	0	15
32	T-3	41 01 39N	73 43 41W	10,000	315	0	15

TABLE A-1
(Page 2 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
33	T-3	41 01 43N	73 43 48W	10,000	300	0	15
34	T-3	41 01 46N	73 43 57W	10,000	285	0	15
35	T-3	41 01 47N	73 44 06W	10,000	270	0	15
36	T-3	41 01 46N	73 44 15W	10,000	255	0	15
37	T-3	41 01 43N	73 44 24W	10,000	240	0	0
38	S-4	41 01 33N	73 44 46W	10,000	240	0	0
39	S-4	40 59 22N	73 49 40W	10,000	240	0	0
40	S-4	40 57 12N	73 54 34W	10,000	240	0	0
41	S-4	40 55 01N	73 59 28W	10,000	240	0	0
42	S-4	40 52 51N	74 04 22W	10,000	240	0	0
43	S-4	40 50 40N	74 09 16W	10,000	240	0	0
44	S-4	40 48 30N	74 14 10W	10,000	240	0	0
45	S-4	40 46 19N	74 19 04W	10,000	240	0	0
46	S-4	40 44 09N	74 23 58W	10,000	240	0	0
47	S-4	40 41 58N	74 28 52W	10,000	240	0	0
48	S-4	40 39 48N	74 33 46W	10,000	240	0	0
49	S-4	40 37 37N	74 38 40W	10,000	240	0	0
50	S-4	40 35 27N	74 43 34W	10,000	240	0	0
51	T-4	40 35 24N	74 43 43W	10,000	255	0	-15
52	T-4	40 35 23N	74 43 52W	10,000	270	0	-15
53	T-4	40 35 24N	74 44 01W	10,000	285	0	-15
54	T-4	40 35 27N	74 44 10W	10,000	300	0	-15
55	T-4	40 35 31N	74 44 17W	10,000	315	0	-15
56	T-4	40 35 37N	74 44 23W	10,000	330	0	-15
57	T-4	40 35 43N	74 44 27W	10,000	345	0	-15
58	T-4	40 35 51N	74 44 28W	10,000	360	0	-15
59	T-4	40 35 58N	74 44 27W	10,000	15	0	-15
60	T-4	40 36 00N	74 44 26W	10,000	18	0	0
61	S-5	40 39 05N	74 43 08W	10,000	18	0	0
62	S-5	40 43 13N	74 41 23W	10,000	18	0	0
63	S-5	40 47 21N	74 39 38W	10,000	18	0	0
64	S-5	40 51 30N	74 37 53W	10,000	18	0	0

TABLE A-1
(Page 3 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
65	S-5	40 55 38N	74 36 08W	10,000	18	0	0
66	S-5	40 59 46N	74 34 23W	10,000	18	0	0
67	R-1	41 00 36N	74 34 02W	10,000	18	0	- 15
68	R-1	41 01 26N	74 33 41W	10,000	18	0	- 30
69	R-1	41 02 16N	74 33 20W	10,000	18	0	- 45
70	R-1	41 03 06N	74 32 59W	10,000	18	0	- 60
71	R-1	41 03 56N	74 32 38W	10,000	18	0	- 75
72	R-1	41 04 46N	74 32 17W	10,000	18	0	- 90
73	R-2	41 05 36N	74 31 56W	10,000	18	0	-105
74	R-2	41 06 26N	74 31 35W	10,000	18	0	-120
75	R-2	41 07 16N	74 31 14W	10,000	18	0	-135
76	R-2	41 08 06N	74 30 53W	10,000	18	0	-150
77	R-2	41 08 56N	74 30 32W	10,000	18	0	-165
78	R-2	41 09 46N	74 30 11W	10,000	18	0	-180
79	R-3	41 10 36N	74 29 50W	10,000	18	0	-195
80	R-3	41 11 26N	74 29 29W	10,000	18	0	-210
81	R-3	41 12 16N	74 29 08W	10,000	18	0	-225
82	R-3	41 13 06N	74 28 47W	10,000	18	0	-240
83	R-3	41 13 56N	74 28 26W	10,000	18	0	-255
84	R-3	41 14 46N	74 28 05W	10,000	18	0	-270
85	R-4	41 15 36N	74 27 44W	10,000	18	0	-285
86	R-4	41 16 26N	74 27 23W	10,000	18	0	-300
87	R-4	41 17 16N	74 27 02W	10,000	18	0	-315
88	R-4	41 18 06N	74 26 41W	10,000	18	0	-330
89	R-4	41 18 56N	74 26 20W	10,000	18	0	-345
90	R-4	41 19 46N	74 25 59W	10,000	18	0	-360
91	S-6	41 20 36N	74 25 38W	10,000	18	0	0
92	S-6	41 24 44N	74 23 53W	10,000	18	0	0
93	S-6	41 28 52N	74 22 08W	10,000	18	0	0
94	S-6	41 33 00N	74 20 23W	10,000	18	0	0
95	S-6	41 37 08N	74 18 38W	10,000	18	0	0
96	S-6	41 41 16N	74 16 53W	10,000	18	0	0

TABLE A-1
(Page 4 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
97	L-1	41 42 06N	74 16 32W	10,000	18	-15	0
98	L-1	41 42 56N	74 16 11W	10,000	18	-30	0
99	L-1	41 43 46N	74 15 50W	10,000	18	-45	0
100	L-1	41 44 36N	74 15 29W	10,000	18	-60	0
101	L-1	41 45 26N	74 15 08W	10,000	18	-75	0
102	L-1	41 46 16N	74 14 47W	10,000	18	-90	0
103	L-2	41 47 06N	74 14 26W	10,000	198	75	180
104	L-2	41 47 56N	74 14 05W	10,000	198	60	180
105	L-2	41 48 46N	73 13 44W	10,000	198	45	180
106	L-2	41 49 36N	74 13 23W	10,000	198	30	180
107	L-2	41 50 26N	74 13 02W	10,000	198	15	180
108	L-2	41 51 16N	74 12 41W	10,000	198	0	180
109	L-3	41 52 06N	74 12 20W	10,000	198	-15	180
110	L-3	41 52 56N	74 11 59W	10,000	198	-30	180
111	L-3	41 53 46N	74 11 38W	10,000	198	-45	180
112	L-3	41 54 36N	74 11 17W	10,000	198	-60	180
113	L-3	41 55 26N	74 10 56W	10,000	198	-75	180
114	L-3	41 56 16N	74 10 35W	10,000	198	-90	180
115	L-4	41 57 06N	74 10 14W	10,000	18	75	0
116	L-4	41 57 56N	74 09 53W	10,000	18	60	0
117	L-4	41 58 46N	74 09 32W	10,000	18	45	0
118	L-4	41 59 36N	74 09 11W	10,000	18	30	0
119	L-4	42 00 26N	74 08 50W	10,000	18	15	0
120	L-4	42 01 16N	74 08 29W	10,000	18	0	0
121	S-7	42 02 06N	74 08 08W	10,000	18	0	0
122	S-7	42 06 14N	74 06 23W	10,000	18	0	0
123	S-7	42 10 22N	74 04 38W	10,000	18	0	0
124	S-7	42 14 30N	74 02 53W	10,000	18	0	0
125	S-7	42 18 38N	74 01 08W	10,000	18	0	0
126	S-7	42 21 23N	73 59 58W	9,000	18	-15	0
127	S-7	42 24 08N	73 58 48W	8,000	18	-15	0
128	S-7	42 26 53N	73 57 38W	7,000	18	-15	0

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
129	S-7	42 29 38N	73 56 28W	6,000	18	-15	0
130	S-7	42 32 23N	73 55 18W	5,000	18	-15	0
131	S-7	42 35 08N	73 54 08W	4,000	18	-15	0
132	S-7	42 37 53N	73 52 58W	3,000	18	-15	0
133	S-7	42 39 15N	73 52 23W	2,500	18	-15	0
134	S-7	42 40 38N	73 51 48W	2,000	18	-15	0
135	S-7	42 42 01N	73 51 13W	1,500	18	-15	0
136	S-7	42 43 23N	73 50 38W	1,000	18	-15	0
137	S-7	42 44 46N	73 50 03W	500	18	-15	0
138	S-8	42 43 32N	73 47 59W	500	180	15	0
139	S-8	42 42 05N	73 47 59W	1,000	180	15	0
140	S-8	42 40 38N	73 47 59W	1,500	180	15	0
141	S-8	42 39 11N	73 47 59W	2,000	180	15	0
142	S-8	42 37 44N	73 47 59W	2,500	180	15	0
143	S-8	42 36 17N	73 47 59W	3,000	180	15	0
144	S-8	42 33 23N	73 47 59W	4,000	180	15	0
145	S-8	42 30 29N	73 47 59W	5,000	180	15	0
146	S-8	42 27 35N	73 47 59W	6,000	180	15	0
147	S-8	42 24 41N	73 47 59W	7,000	180	15	0
148	S-8	42 21 47N	73 47 59W	8,000	180	15	0
149	S-8	42 18 53N	73 47 59W	9,000	180	15	0
150	S-8	42 15 59N	73 47 59W	10,000	180	0	0
151	S-8	42 14 32N	73 47 59W	10,000	180	0	0
152	S-8	42 10 11N	73 47 59W	10,000	180	0	0
153	S-8	42 05 50N	73 47 59W	10,000	180	0	0
154	S-8	42 01 29N	73 47 59W	10,000	180	0	0
155	S-8	41 57 08N	73 47 59W	10,000	180	0	0
156	S-8	41 52 47N	73 47 59W	10,000	180	0	0
157	S-8	41 48 26N	73 47 59W	10,000	180	0	0
158	S-8	41 44 05N	73 47 59W	10,000	180	0	0
159	S-8	41 42 06N	73 47 59W	10,000	180	0	0
160	T-5	41 41 59N	73 47 58W	10,000	165	0	15

TABLE A-1
(Page 6 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
161	T-5	41 41 52N	73 47 54W	10,000	150	0	15
162	T-5	41 41 46N	73 47 48W	10,000	135	0	15
163	T-5	41 41 42N	73 47 41W	10,000	120	0	15
164	T-5	41 41 39N	73 47 32W	10,000	105	0	15
165	T-5	41 41 38N	73 47 23W	10,000	90	0	0
166	H-K	41 41 38N	73 47 04W	10,000	90	0	0
167	H-K1	41 41 34N	73 46 29W	10,000	105	0	-15
168	H-K1	41 41 24N	73 45 56W	10,000	120	0	-15
169	H-K1	41 41 07N	73 45 28W	10,000	135	0	-15
170	H-K1	41 40 46N	73 45 06W	10,000	150	0	-15
171	H-K1	41 40 21N	73 44 53W	10,000	165	0	-15
172	H-K1	41 39 54N	73 44 48W	10,000	180	0	-15
173	H-K2	41 39 27N	73 44 53W	10,000	195	0	-15
174	H-K2	41 39 02N	73 45 06W	10,000	210	0	-15
175	H-K2	41 38 40N	73 45 28W	10,000	225	0	-15
176	H-K2	41 38 24N	73 45 56W	10,000	240	0	-15
177	H-K2	41 38 13N	73 46 29W	10,000	255	0	-15
178	H-K2	41 38 10N	73 47 04W	10,000	270	0	0
179	H-K	41 38 10N	73 48 12W	10,000	270	0	0
180	H-K	41 38 10N	73 49 20W	10,000	270	0	0
181	H-K	41 38 10N	73 50 28W	10,000	270	0	0
182	H-K	41 38 10N	73 51 36W	10,000	270	0	0
183	H-K3	41 38 14N	73 52 11W	10,000	285	0	-15
184	H-K3	41 38 24N	73 52 44W	10,000	300	0	-15
185	H-K3	41 38 41N	73 53 12W	10,000	315	0	-15
186	H-K3	41 39 02N	73 53 34W	10,000	330	0	-15
187	H-K3	41 39 27N	73 53 47W	10,000	345	0	-15
188	H-K3	41 39 54N	73 53 52W	10,000	360	0	-15
189	H-K4	41 40 21N	73 53 47W	10,000	15	0	-15
190	H-K4	41 40 46N	73 53 34W	10,000	30	0	-15
191	H-K4	41 41 08N	73 53 12W	10,000	45	0	-15
192	H-K4	41 41 24N	73 52 44W	10,000	60	0	-15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
193	H-K4	41 41 35N	73 52 11W	10,000	75	0	-15
194	H-K4	41 41 38N	73 51 36W	10,000	90	0	0
195	H-K	41 41 38N	73 50 28W	10,000	90	0	0
196	H-K	41 41 38N	73 49 20W	10,000	90	0	0
197	H-K	41 41 38N	73 48 12W	10,000	90	0	0
198	H-K	41 41 38N	73 47 04W	10,000	90	0	0
199	H-K1	41 41 34N	73 46 29W	10,000	105	0	-15
200	H-K1	41 41 24N	73 45 56W	10,000	120	0	-15
201	H-K1	41 41 07N	73 45 28W	10,000	135	0	-15
202	H-K1	41 40 46N	73 45 06W	10,000	150	0	-15
203	H-K1	41 40 39N	73 45 02W	10,000	154	0	0
204	S-9	41 36 44N	73 42 33W	10,000	154	0	0
205	S-9	41 32 50N	73 40 04W	10,000	154	0	0
206	S-9	41 28 55N	73 37 35W	10,000	154	0	0
207	S-9	41 25 01N	73 35 06W	10,000	154	0	0
208	S-9	41 21 06N	73 32 37W	10,000	154	0	0
209	S-9	41 19 10N	73 31 24W	10,000	154	0	0
210	T-6	41 19 07N	73 31 22W	10,000	160	0	-15
211	T-6	41 19 03N	73 31 21W	10,000	170	0	-15
212	T-6	41 18 58N	73 31 20W	10,000	180	0	-15
213	T-6	41 18 51N	73 31 21W	10,000	195	0	-15
214	T-6	41 18 44N	73 31 25W	10,000	210	0	-15
215	T-6	41 18 38N	73 31 31W	10,000	225	0	-15
216	T-6	41 18 34N	73 31 38W	10,000	240	0	-15
217	T-6	41 18 31N	73 31 47W	10,000	255	0	-15
218	T-6	41 18 30N	73 31 56W	10,000	270	0	0
219	H-C	41 18 30N	73 32 37W	10,000	270	0	0
220	H-C	41 18 30N	73 33 45W	10,000	270	0	0
221	H-C	41 18 30N	73 33 53W	10,000	270	0	0
222	H-C	41 18 30N	73 36 01W	10,000	270	0	0
223	H-C	41 18 30N	73 37 09W	10,000	270	0	0
224	H-C1	41 18 26N	73 37 44W	10,000	255	0	15

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(Page 8 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
225	H-C1	41 18 16N	73 38 17W	10,000	240	0	15
226	H-C1	41 17 59N	73 38 45W	10,000	225	0	15
227	H-C1	41 17 38N	73 39 07W	10,000	210	0	15
228	H-C1	41 17 13N	73 39 20W	10,000	195	0	15
229	H-C1	41 16 46N	73 39 25W	10,000	180	0	15
230	H-C2	41 16 19N	73 39 20W	10,000	165	0	15
231	H-C2	41 15 54N	73 39 07W	10,000	150	0	15
232	H-C2	41 15 32N	73 38 45W	10,000	135	0	15
233	H-C2	41 15 16N	73 38 17W	10,000	120	0	15
234	H-C2	41 15 05N	73 37 44W	10,000	105	0	15
235	H-C2	41 15 02N	73 37 09W	10,000	90	0	0
236	H-C	41 15 02N	73 36 01W	10,000	90	0	0
237	H-C	41 15 02N	73 34 53W	10,000	90	0	0
238	H-C	41 15 02N	73 33 45W	10,000	90	0	0
239	H-C	41 15 02N	73 32 37W	10,000	90	0	0
240	H-C3	41 15 06N	73 32 02W	10,000	75	0	15
241	H-C3	41 15 16N	73 31 29W	10,000	60	0	15
242	H-C3	41 15 33N	73 31 01W	10,000	45	0	15
243	H-C3	41 15 54N	73 30 39W	10,000	30	0	15
244	H-C3	41 16 19N	73 30 26W	10,000	15	0	15
245	H-C3	41 16 46N	73 30 21W	10,000	0	0	15
246	H-C4	41 17 13N	73 30 26W	10,000	345	0	15
247	H-C4	41 17 38N	73 30 39W	10,000	330	0	15
248	H-C4	41 18 00N	73 31 01W	10,000	315	0	15
249	H-C4	41 18 16N	73 31 29W	10,000	300	0	15
250	H-C4	41 18 27N	73 32 02W	10,000	285	0	15
251	H-C4	41 18 30N	73 32 37W	10,000	270	0	0
252	H-C	41 18 30N	73 33 45W	10,000	270	0	0
253	H-C	41 18 30N	73 34 53W	10,000	270	0	0
254	H-C	41 18 30N	73 36 01W	10,000	270	0	0
255	H-C	41 18 30N	73 37 09W	10,000	270	0	0
256	H-C1	41 18 26N	73 37 44W	10,000	255	0	15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
257	H-C1	41 18 16N	73 38 17W	10,000	240	0	15
258	H-C1	41 17 59N	73 38 45W	10,000	225	0	15
259	H-C1	41 17 38N	73 39 07W	10,000	210	0	15
260	H-C1	41 17 13N	73 39 20W	10,000	195	0	15
261	H-C1	41 17 07N	73 39 22W	10,000	192	0	0
262	S-10	41 12 52N	73 40 33W	10,000	192	0	0
263	S-10	41 08 36N	73 41 43W	10,000	192	0	0
264	S-10	41 06 30N	73 42 18W	10,000	192	0	0
265	S-10	41 03 40N	73 43 05W	9,000	192	-15	0
266	S-10	41 00 50N	73 43 52W	8,000	192	-15	0
267	S-10	40 58 00N	73 44 39W	7,000	192	-15	0
268	S-10	40 55 10N	73 45 26W	6,000	192	-15	0
269	S-10	40 52 20N	73 46 13W	5,000	192	-15	0
270	S-10	40 51 57N	73 46 20W	4,866	192	-15	0
271	T-7	40 51 55N	73 46 20W	4,857	189	-15	15
272	T-7	40 51 54N	73 46 20W	4,849	186	-15	15
273	T-7	40 51 53N	73 46 20W	4,841	183	-15	15
274	T-7	40 51 51N	73 46 21W	4,833	180	-15	0
275	S-11	40 50 53N	73 46 21W	4,500	180	-15	0
276	S-11	40 49 26N	73 46 21W	4,000	180	-15	0
277	S-11	40 47 59N	73 46 21W	3,500	180	-15	0
278	S-11	40 46 32N	73 46 21W	3,000	180	-15	0
279	S-11	40 45 05N	73 46 21W	2,500	180	-15	0
280	S-11	40 43 38N	73 46 21W	2,000	180	-15	0
281	S-11	40 42 11N	73 46 21W	1,500	180	-15	0
282	S-11	40 40 44N	73 46 21W	1,000	180	-15	0
283	S-11	40 39 17N	73 46 21W	500	180	-15	0

AIRCRAFT POSITIONS DEFINING THE FLIGHT PATH FOR THE BOEING 727, BOEING 747 AND THE F-4H
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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
1	S-1	40 45 32N	73 51 59W	770	180	15	0
2	S-1	40 44 05N	73 51 59W	1,540	180	15	0
3	S-1	40 43 51N	73 51 59W	1,663	180	15	0
4	T-1	40 43 32N	73 51 56W	1,830	165	15	15
5	T-1	40 43 15N	73 51 46W	2,000	150	15	15
6	T-1	40 43 00N	73 51 32W	2,160	135	15	15
7	T-1	40 42 49N	73 51 12W	2,326	120	15	15
8	T-1	40 42 42N	73 50 50W	2,492	105	15	15
9	T-1	40 42 39N	73 50 25W	2,658	90	15	0
10	S-2	40 42 39N	73 49 51W	2,891	90	15	0
11	S-2	40 42 39N	73 47 58W	3,660	90	15	0
12	S-2	40 42 39N	73 46 05W	4,429	90	15	0
13	S-2	40 42 39N	73 45 34W	4,638	90	15	0
14	S-2	40 42 39N	73 45 04W	4,842	90	15	0
15	T-2	40 42 39N	73 44 40W	5,008	75	15	15
16	T-2	40 42 49N	73 44 17W	5,174	60	15	15
17	T-2	40 43 00N	73 43 58W	5,340	45	15	15
18	T-2	40 43 15N	73 43 43W	5,506	30	15	15
19	T-2	40 43 32N	73 43 34W	5,672	15	15	15
20	T-2	40 43 51N	73 43 30W	5,839	0	15	0
21	S-3	40 44 32N	73 43 30W	6,199	0	15	0
22	S-3	40 45 13N	73 43 30W	6,565	0	15	0
23	S-3	40 46 40N	73 43 30W	7,334	0	15	0
24	S-3	40 49 34N	73 43 30W	8,873	0	15	0
25	S-3	40 52 27N	73 43 30W	9,500	0	15	0
26	S-3	40 55 21N	73 43 30W	10,000	0	0	0
27	S-3	40 58 15N	73 43 30W	10,000	0	0	0
28	S-3	41 01 08N	73 43 30W	10,000	0	0	0
29	S-3	41 02 00N	73 43 30W	10,000	0	0	0
30	T-3	41 02 19N	73 43 33W	10,000	345	0	15
31	T-3	41 02 36N	73 43 43W	10,000	330	0	15
32	T-3	41 02 51N	73 43 57W	10,000	315	0	15
33	T-3	41 03 02N	73 44 17W	10,000	300	0	15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
34	T-3	41 03 09N	73 44 39W	10,000	285	0	15
35	T-3	41 03 12N	73 45 04W	10,000	270	0	15
36	T-3	41 03 10N	73 45 28W	10,000	255	0	15
37	T-3	41 03 02N	73 45 51W	10,000	240	0	15
38	T-3	41 02 51N	73 46 10W	10,000	225	0	15
39	T-3	41 02 36N	73 46 25W	10,000	210	0	15
40	T-3	41 02 19N	73 46 34W	10,000	195	0	15
41	T-3	41 02 00N	73 46 37W	10,000	180	0	15
42	T-3	41 01 24N	73 46 37W	10,000	180	0	15
43	T-3	41 01 05N	73 46 40W	10,000	195	0	-15
44	T-3	41 00 48N	73 46 50W	10,000	210	0	-15
45	T-3	41 00 33N	73 47 04W	10,000	225	0	-15
46	T-3	41 00 22N	73 47 24W	10,000	240	0	0
47	S-4	40 59 22N	73 49 40W	10,000	240	0	0
48	S-4	40 57 12N	73 54 34W	10,000	240	0	0
49	S-4	40 55 01N	73 59 28W	10,000	240	0	0
50	S-4	40 52 51N	74 04 22W	10,000	240	0	0
51	S-4	40 50 40N	74 09 16W	10,000	240	0	0
52	S-4	40 48 30N	74 14 10W	10,000	240	0	0
53	S-4	40 46 19N	74 19 04W	10,000	240	0	0
54	S-4	40 44 09N	74 23 58W	10,000	240	0	0
55	S-4	40 41 58N	74 28 52W	10,000	240	0	0
56	S-4	40 39 48N	74 33 46W	10,000	240	0	0
57	S-4	40 37 37N	74 38 40W	10,000	240	0	0
58	S-4	40 36 24N	74 41 24W	10,000	240	0	0
59	T-4	40 36 22N	74 41 48W	10,000	255	0	-15
60	T-4	40 36 14N	74 42 11W	10,000	270	0	-15
61	T-4	40 36 16N	74 42 35W	10,000	285	0	-15
62	T-4	40 36 24N	74 42 58W	10,000	300	0	-15
63	T-4	40 36 35N	74 43 17W	10,000	315	0	-15
64	T-4	40 36 50N	74 43 32W	10,000	330	0	-15
65	T-4	40 37 07N	74 43 41W	10,000	345	0	-15
66	T-4	40 37 26N	74 43 45W	10,000	360	0	-15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
67	T-4	40 37 45N	74 43 42W	10,000	15	0	-15
68	T-4	40 37 48N	74 43 40W	10,000	18	0	0
69	S-5	40 39 03N	74 43 08W	10,000	18	0	0
70	S-5	40 43 13N	74 41 23W	10,000	18	0	0
71	S-5	40 47 21N	74 39 38W	10,000	18	0	0
72	S-5	40 51 30N	74 37 53W	10,000	18	0	0
73	S-5	40 55 38N	74 36 08W	10,000	18	0	0
74	S-5	40 59 46N	74 34 23W	10,000	18	0	0
75	R-1	41 00 36N	74 34 02W	10,000	18	0	-15
76	R-1	41 01 26N	74 33 41W	10,000	18	0	-30
77	R-1	41 02 16N	74 33 20W	10,000	18	0	-45
78	R-1	41 03 06N	74 32 59W	10,000	18	0	-60
79	R-1	41 03 56N	74 32 38W	10,000	18	0	-75
80	R-1	41 04 46N	74 32 17W	10,000	18	0	-90
81	R-2	41 05 36N	74 31 56W	10,000	18	0	-105
82	R-2	41 06 26N	74 31 35W	10,000	18	0	-120
83	R-2	41 07 16N	74 31 14W	10,000	18	0	-135
84	R-2	41 08 06N	74 30 53W	10,000	18	0	-150
85	R-2	41 08 56N	74 30 32W	10,000	18	0	-165
86	R-2	41 09 46N	74 30 12W	10,000	18	0	-180
87	R-3	41 10 36N	74 29 50W	10,000	18	0	-195
88	R-3	41 11 26N	74 29 29W	10,000	18	0	-210
89	R-3	41 12 16N	74 29 08W	10,000	18	0	-225
90	R-3	41 13 06N	74 28 47W	10,000	18	0	-240
91	R-3	41 13 56N	74 28 26W	10,000	18	0	-255
92	R-3	41 14 46N	74 28 05W	10,000	18	0	-270
93	R-4	41 15 36N	74 27 44W	10,000	18	0	-285
94	R-4	41 16 26N	74 27 23W	10,000	18	0	-300
95	R-4	41 17 16N	74 27 02W	10,000	18	0	-315
96	R-4	41 18 06N	74 26 41W	10,000	18	0	-330
97	R-4	41 18 56N	74 26 20W	10,000	18	0	-345
98	R-4	41 19 46N	74 25 59W	10,000	18	0	-360
99	S-6	41 20 36N	74 25 38W	10,000	18	0	0

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(Page 4 of 9)

Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
100	S-6	41 24 44N	74 23 53W	10,000	18	0	0
101	S-6	41 28 52N	74 22 08W	10,000	18	0	0
102	S-6	41 33 00N	74 20 23W	10,000	18	0	0
103	S-6	41 37 08N	74 18 38W	10,000	18	0	0
104	S-6	41 41 16N	74 16 53W	10,000	18	0	0
105	L-1	41 42 06N	74 16 32W	10,000	18	-15	0
106	L-1	41 42 56N	74 16 11W	10,000	18	-30	0
107	L-1	41 43 46N	74 15 50W	10,000	18	-45	0
108	L-1	41 44 36N	74 15 29W	10,000	18	-60	0
109	L-1	41 45 26N	74 15 08W	10,000	18	-75	0
110	L-1	41 46 16N	74 14 47W	10,000	18	-90	0
111	L-2	41 47 06N	74 14 26W	10,000	198	75	180
112	L-2	41 47 56N	74 14 05W	10,000	198	60	180
113	L-2	41 48 46N	74 13 44W	10,000	198	45	180
114	L-2	41 49 36N	74 13 23W	10,000	198	30	180
115	L-2	41 50 26N	74 13 02W	10,000	198	15	180
116	L-2	41 51 16N	74 12 41W	10,000	198	0	180
117	L-3	41 52 06N	74 12 20W	10,000	198	-15	180
118	L-3	41 52 56N	74 11 59W	10,000	198	-30	180
119	L-3	41 53 46N	74 11 38W	10,000	198	-45	180
120	L-3	41 54 36N	74 11 17W	10,000	198	-60	180
121	L-3	41 55 26N	74 10 56W	10,000	198	-75	180
122	L-3	41 56 16N	74 10 35W	10,000	198	-90	180
123	L-4	41 57 06N	74 10 14W	10,000	18	75	0
124	L-4	41 57 56N	74 09 53W	10,000	18	60	0
125	L-4	41 58 46N	74 09 32W	10,000	18	45	0
126	L-4	41 59 36N	74 09 11W	10,000	18	30	0
127	L-4	42 00 26N	74 08 50W	10,000	18	15	0
128	L-4	42 01 16N	74 08 29W	10,000	18	0	0
129	S-7	42 02 06N	74 08 08W	10,000	18	0	0
130	S-7	42 06 14N	74 06 23W	10,000	18	0	0
131	S-7	42 10 22N	74 04 38W	10,000	18	0	0
132	S-7	42 14 30N	74 02 53W	10,000	18	0	0
133	S-7	42 18 38N	74 01 08W	10,000	18	0	0

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
134	S-7	42 21 23N	73 59 58W	10,000	18	0	0
135	S-7	42 24 08N	73 58 48W	10,000	18	0	0
136	S-7	42 26 53N	73 57 38W	10,000	18	0	0
137	S-7	42 29 38N	73 56 28W	9,240	18	-10	0
138	S-7	42 32 23N	73 55 18W	7,700	18	-10	0
139	S-7	42 35 08N	73 54 08W	6,160	18	-10	0
140	S-7	42 37 53N	73 52 58W	4,620	18	-10	0
141	S-7	42 39 15N	73 52 25W	3,850	18	-10	0
142	S-7	42 40 38N	73 51 48W	3,080	18	-10	0
143	S-7	42 42 01N	73 51 13W	2,310	18	-10	0
144	S-7	42 43 23N	73 50 38W	1,540	18	-10	0
145	S-7	42 44 46N	73 50 03W	770	18	-10	0
146	S-8	42 43 32N	73 47 59W	770	180	15	0
147	S-8	42 42 05N	73 47 59W	1,540	180	15	0
148	S-8	42 40 38N	73 47 59W	2,310	180	15	0
149	S-8	42 39 11N	73 47 59W	3,080	180	15	0
150	S-8	42 37 44N	73 47 59W	3,850	180	15	0
151	S-8	42 36 17N	73 47 59W	4,620	180	15	0
152	S-8	42 33 23N	73 47 59W	6,160	180	15	0
153	S-8	42 30 29N	73 47 59W	7,700	180	15	0
154	S-8	42 27 35N	73 47 59W	9,240	180	15	0
155	S-8	42 24 41N	73 47 59W	10,000	180	0	0
156	S-8	42 21 47N	73 47 59W	10,000	180	0	0
157	S-8	42 18 53N	73 47 59W	10,000	180	0	0
158	S-8	42 15 59N	73 47 59W	10,000	180	0	0
159	S-8	42 14 32N	73 47 59W	10,000	180	0	0
160	S-8	42 10 11N	73 47 59W	10,000	180	0	0
161	S-8	42 05 50N	73 47 59W	10,000	180	0	0
162	S-8	42 01 29N	73 47 59W	10,000	180	0	0
163	S-8	41 57 08N	73 47 59W	10,000	180	0	0
164	S-8	41 52 47N	73 47 59W	10,000	180	0	0
165	S-8	41 48 26N	73 47 59W	10,000	180	0	0
166	S-8	41 44 05N	73 47 59W	10,000	180	0	0

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
167	S-8	41 42 31N	73 47 59W	10,000	180	0	0
168	T-5	41 42 12N	73 47 56W	10,000	165	0	15
169	T-5	41 41 55N	73 47 46W	10,000	150	0	15
170	T-5	41 41 40N	73 47 32W	10,000	135	0	15
171	T-5	41 41 29N	73 47 12W	10,000	120	0	15
172	T-5	41 41 22N	73 46 50W	10,000	105	0	15
173	T-5	41 41 19N	73 46 25W	10,000	90	0	0
174	H-K	41 41 17N	73 46 01W	10,000	105	0	-15
175	H-K	41 41 09N	73 45 38W	10,000	120	0	-15
176	H-K	41 40 58N	73 45 19W	10,000	135	0	-15
177	H-K	41 40 43N	73 45 04W	10,000	150	0	-15
178	H-K1	41 40 39N	73 45 01W	10,000	154	0	-15
179	H-K1	41 40 21N	73 44 53W	10,000	165	0	-15
180	H-K1	41 39 54N	73 44 48W	10,000	180	0	-15
181	H-K2	41 39 27N	73 44 53W	10,000	195	0	-15
182	H-K2	41 39 02N	73 45 06W	10,000	210	0	-15
183	H-K2	41 38 40N	73 45 28W	10,000	225	0	-15
184	H-K2	41 38 24N	73 45 56W	10,000	240	0	-15
185	H-K2	41 38 13N	73 46 29W	10,000	255	0	-15
186	H-K2	41 38 10N	73 47 04W	10,000	270	0	0
187	H-K	41 38 10N	73 48 12W	10,000	270	0	0
188	H-K	41 38 10N	73 49 20W	10,000	270	0	0
189	H-K	41 38 10N	73 50 28W	10,000	270	0	0
190	H-K	41 38 10N	73 51 36W	10,000	270	0	0
191	H-K3	41 38 14N	73 52 11W	10,000	285	0	-15
192	H-K3	41 38 24N	73 52 44W	10,000	300	0	-15
193	H-K3	41 38 43N	73 53 12W	10,000	315	0	-15
194	H-K3	41 39 02N	73 53 34W	10,000	330	0	-15
195	H-K3	41 39 27N	73 53 47W	10,000	345	0	-15
196	H-K3	41 39 54N	73 53 52W	10,000	360	0	-15
197	H-K4	41 40 21N	73 53 47W	10,000	15	0	-15
198	H-K4	41 40 46N	73 53 34W	10,000	30	0	-15
199	H-K4	41 41 08N	73 53 12W	10,000	45	0	-15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
233	H-C1	41 18 16N	73 38 17W	10,000	240	0	15
234	H-C1	41 17 59N	73 38 45W	10,000	225	0	15
235	H-C1	41 17 38N	73 39 07W	10,000	210	0	15
236	H-C1	41 17 13N	73 39 20W	10,000	195	0	15
237	H-C1	41 16 46N	73 39 25W	10,000	180	0	15
238	H-C2	41 16 19N	73 39 20W	10,000	165	0	15
239	H-C2	41 15 54N	73 39 07W	10,000	150	0	15
240	H-C2	41 15 32N	73 38 45W	10,000	135	0	15
241	H-C2	41 15 16N	73 38 17W	10,000	120	0	15
242	H-C2	41 15 05N	73 37 44W	10,000	105	0	15
243	H-C2	41 15 02N	73 37 09W	10,000	90	0	0
244	H-C	41 15 02N	73 36 01W	10,000	90	0	0
245	H-C	41 15 02N	73 34 53W	10,000	90	0	0
246	H-C	41 15 02N	73 33 45W	10,000	90	0	0
247	H-C	41 15 02N	73 32 37W	10,000	90	0	0
248	H-C3	41 15 06N	73 32 02W	10,000	75	0	15
249	H-C3	41 15 16N	73 31 29W	10,000	60	0	15
250	H-C3	41 15 33N	73 31 01W	10,000	45	0	15
251	H-C3	41 15 54N	73 30 39W	10,000	30	0	15
252	H-C3	41 16 19N	73 30 26W	10,000	15	0	15
253	H-C3	41 16 46N	73 30 21W	10,000	0	0	15
254	H-C4	41 17 13N	73 30 26W	10,000	345	0	15
255	H-C4	41 17 38N	73 30 39W	10,000	330	0	15
256	H-C4	41 18 00N	73 31 01W	10,000	315	0	15
257	H-C4	41 18 16N	73 31 29W	10,000	300	0	15
258	H-C4	41 18 27N	73 32 02W	10,000	285	0	15
259	H-C4	41 18 30N	73 32 37W	10,000	270	0	0
260	H-C	41 18 30N	73 33 45W	10,000	270	0	0
261	H-C	41 18 30N	73 34 53W	10,000	270	0	0
262	H-C	41 18 30N	73 36 01W	10,000	270	0	0
263	H-C	41 18 30N	73 37 09W	10,000	270	0	0
264	H-C1	41 18 26N	73 37 44W	10,000	255	0	15
265	H-C1	41 18 16N	73 38 17W	10,000	240	0	15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
200	H-K4	41 41 24N	73 52 44W	10,000	60	0	-15
201	H-K4	41 41 35N	73 52 11W	10,000	75	0	-15
202	H-K4	41 41 38N	73 51 36W	10,000	90	0	0
203	H-K	41 41 38N	73 50 28W	10,000	90	0	0
204	H-K	41 41 38N	73 49 20W	10,000	90	0	0
205	H-K	41 41 38N	73 48 12W	10,000	90	0	0
206	H-K	41 41 38N	73 47 04W	10,000	90	0	0
207	H-K1	41 41 34N	73 46 29W	10,000	105	0	-15
208	H-K1	41 41 24N	73 45 56W	10,000	120	0	-15
209	H-K1	41 41 07N	73 45 28W	10,000	135	0	-15
210	H-K1	41 40 46N	73 45 06W	10,000	150	0	-15
211	H-K1	41 40 39N	73 45 02W	10,000	154	0	0
212	S-9	41 36 44N	73 42 33W	10,000	154	0	0
213	S-9	41 32 50N	73 40 04W	10,000	154	0	0
214	S-9	41 28 55N	73 37 35W	10,000	154	0	0
215	S-9	41 25 01N	73 35 06W	10,000	154	0	0
216	S-9	41 21 06N	73 32 37W	10,000	154	0	0
217	S-9	41 20 13N	73 32 04W	10,000	154	0	0
218	T-6	41 20 06N	73 32 04W	10,000	160	0	-15
219	T-6	41 19 53N	73 31 56W	10,000	170	0	-15
220	T-6	41 19 41N	73 31 55W	10,000	180	0	-15
221	T-6	41 19 22N	73 31 58W	10,000	195	0	-15
222	T-6	41 19 05N	73 32 08W	10,000	210	0	-15
223	T-6	41 18 50N	73 32 22W	10,000	225	0	-15
224	T-6	41 18 39N	73 32 42W	10,000	240	0	-15
225	T-6	41 18 32N	73 33 04W	10,000	255	0	-15
226	T-6	41 18 30N	73 33 29W	10,000	270	0	0
227	H-C	41 18 30N	73 33 37W	10,000	270	0	0
228	H-C	41 18 30N	73 33 45W	10,000	270	0	0
229	H-C	41 18 30N	73 34 53W	10,000	270	0	0
230	H-C	41 18 30N	73 36 01W	10,000	270	0	0
231	H-C	41 18 30N	73 37 09W	10,000	270	0	0
232	H-C1	41 18 26N	73 37 44W	10,000	255	0	15

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Position Number	Path Segment	Latitude (° ' ")	Longitude (° ' ")	Altitude (Ft.)	Heading (Deg.)	Pitch (Deg.)	Roll (Deg.)
266	H-C1	41 17 59N	73 38 45W	10,000	225	0	15
267	H-C1	41 17 38N	73 39 07W	10,000	210	0	15
268	H-C1	41 17 13N	73 39 20W	10,000	195	0	15
269	H-C1	41 17 07N	73 39 22W	10,000	192	0	0
270	S-10	41 12 52N	73 40 33W	10,000	192	0	0
271	S-10	41 08 36N	73 41 43W	10,000	192	0	0
272	S-10	41 06 30N	73 42 18W	10,000	192	0	0
273	S-10	41 03 40N	73 43 05W	10,000	192	0	0
274	S-10	41 00 50N	73 43 52W	10,000	192	0	0
275	S-10	40 58 00N	73 44 39W	10,000	192	0	0
276	S-10	40 55 10N	73 45 26W	9,244	192	-10	0
277	S-10	40 52 20N	73 46 13W	7,703	192	-10	0
278	S-10	40 51 58N	73 46 19W	7,505	192	-10	0
279	T-7	40 51 54N	73 46 20W	7,472	189	-10	15
280	T-7	40 51 51N	73 46 20W	7,438	186	-10	15
281	T-7	40 51 47N	73 46 21W	7,405	183	-10	15
282	T-7	40 51 43N	73 46 21W	7,372	180	-10	0
283	S-11	40 50 53N	73 46 21W	6,930	180	-10	0
284	S-11	40 49 26N	73 46 21W	6,160	180	-10	0
285	S-11	40 47 59N	73 46 21W	5,390	180	-10	0
286	S-11	40 46 32N	73 46 21W	4,620	180	-10	0
287	S-11	40 45 05N	73 46 21W	3,850	180	-10	0
288	S-11	40 43 38N	73 47 21W	3,080	189	-10	0
289	S-11	40 21 11N	73 46 21W	2,310	180	-10	0
290	S-11	40 40 44N	73 46 21W	1,540	180	-10	0
291	S-11	40 39 17N	73 46 21W	770	180	-10	0

APPENDIX B

ATCRBS ANTENNA PATTERNS

ATCRBS antenna patterns for the Cessna 150, Boeing 727, and Boeing 747 aircraft were derived from measured data provided by Lincoln Laboratories. The ATCRBS antenna patterns for the F-4H aircraft are synthesized patterns generated by an ECAC adaptation of the Ohio State University antenna pattern model.

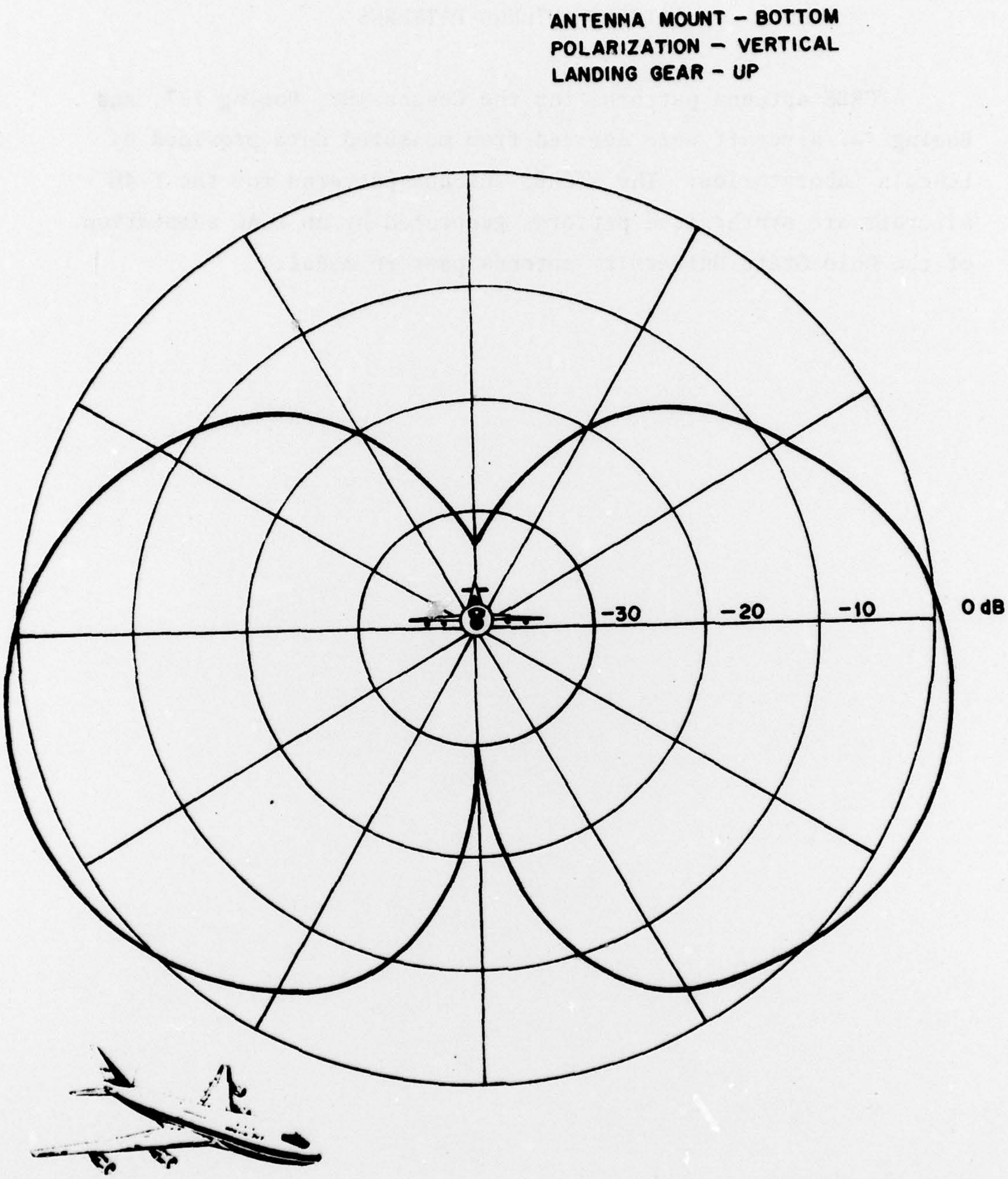

Figure B-1. Boeing 747 roll plane

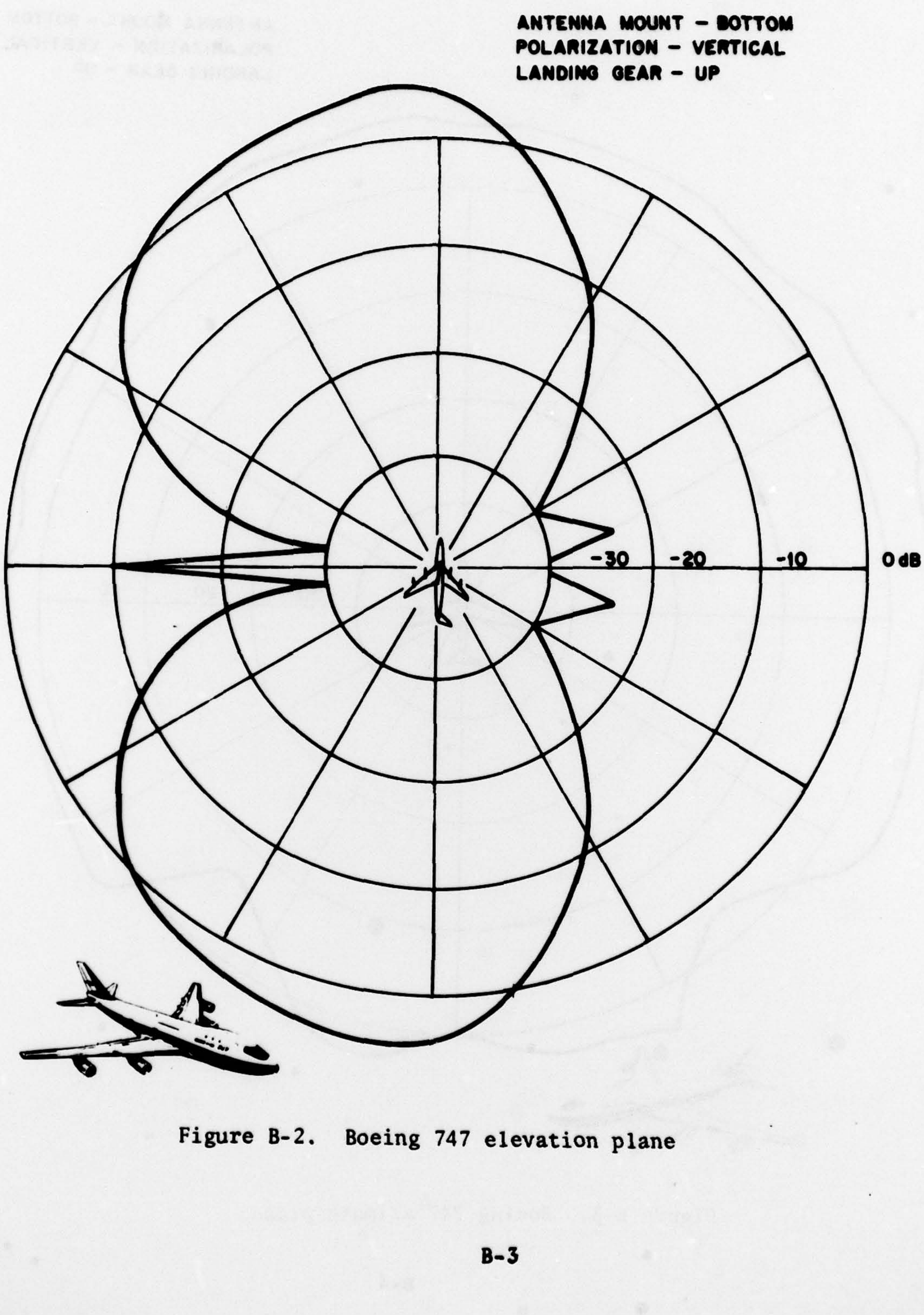

Figure B-2. Boeing 747 elevation plane

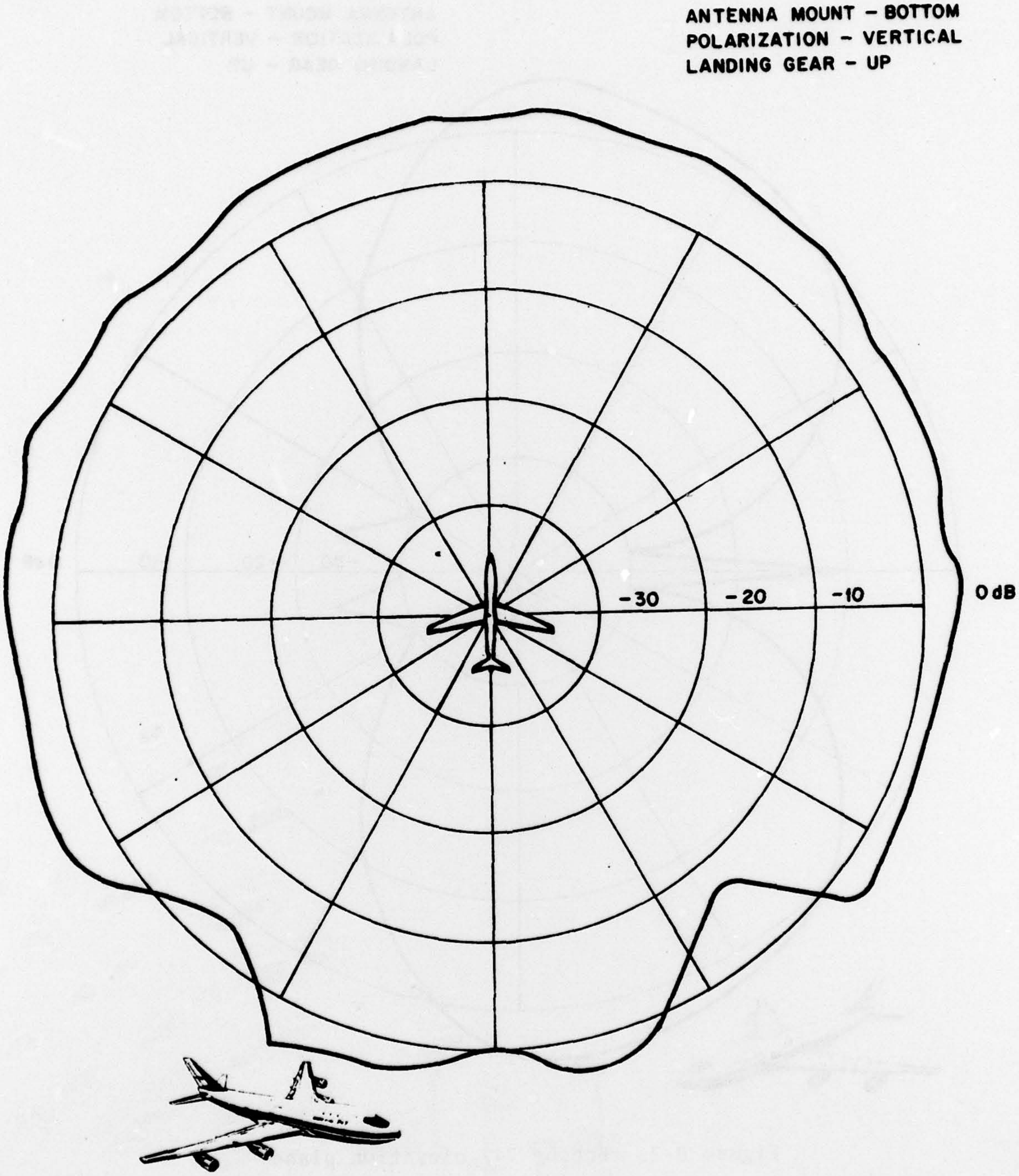

Figure B-3. Boeing 747 azimuth plane

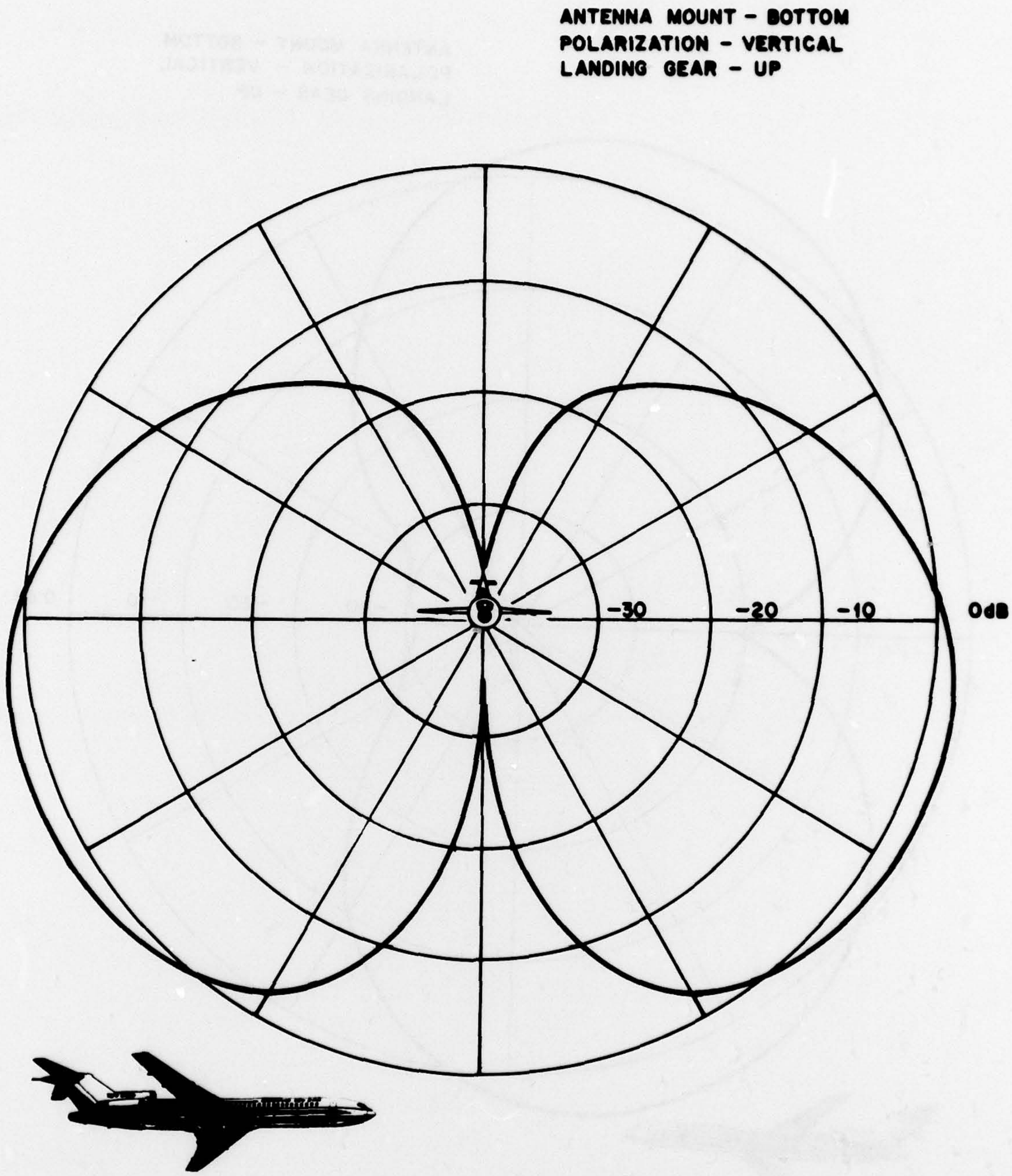

Figure B-4. Boeing 727 roll plane

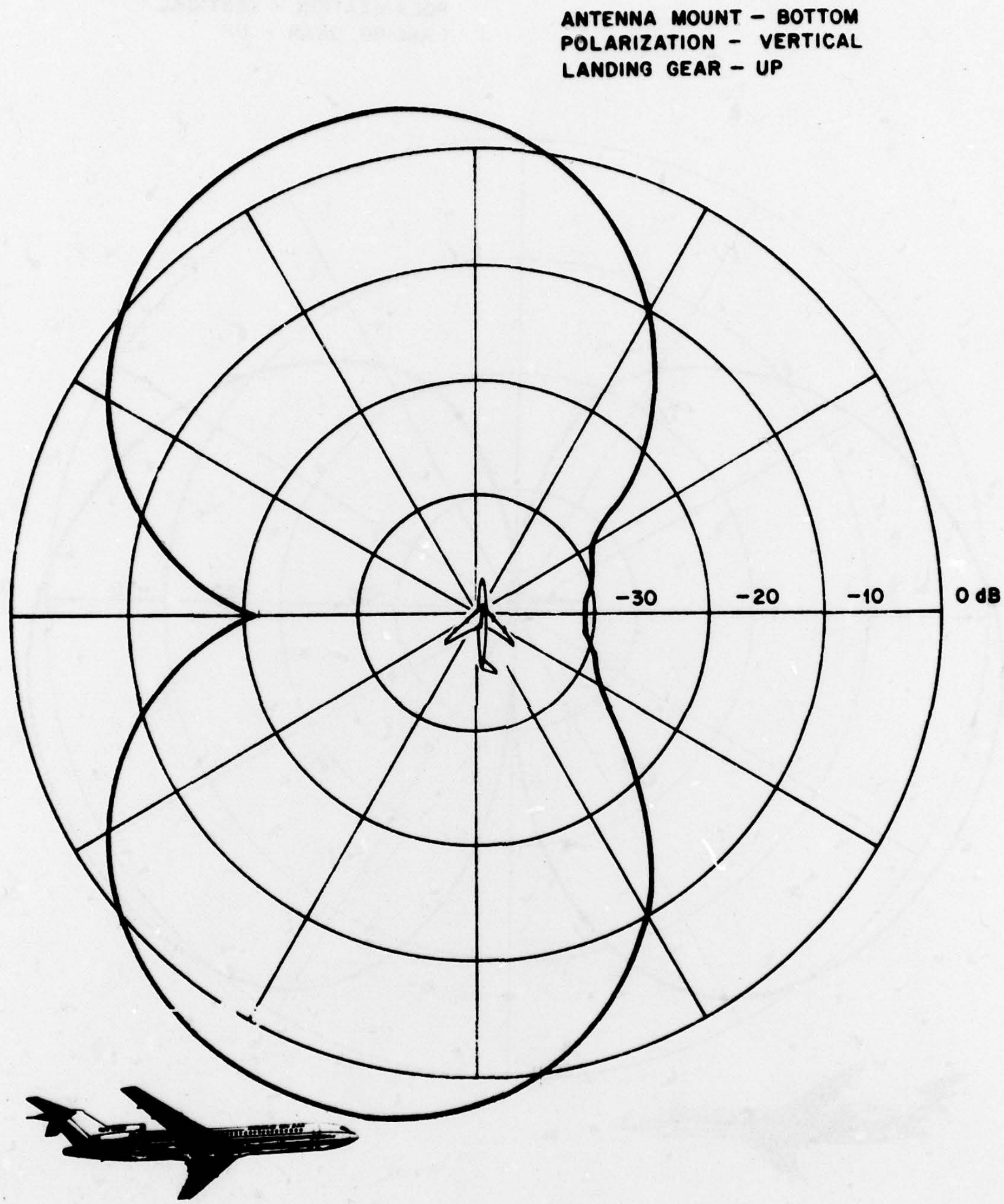

Figure B-5. Boeing 727 elevation plane

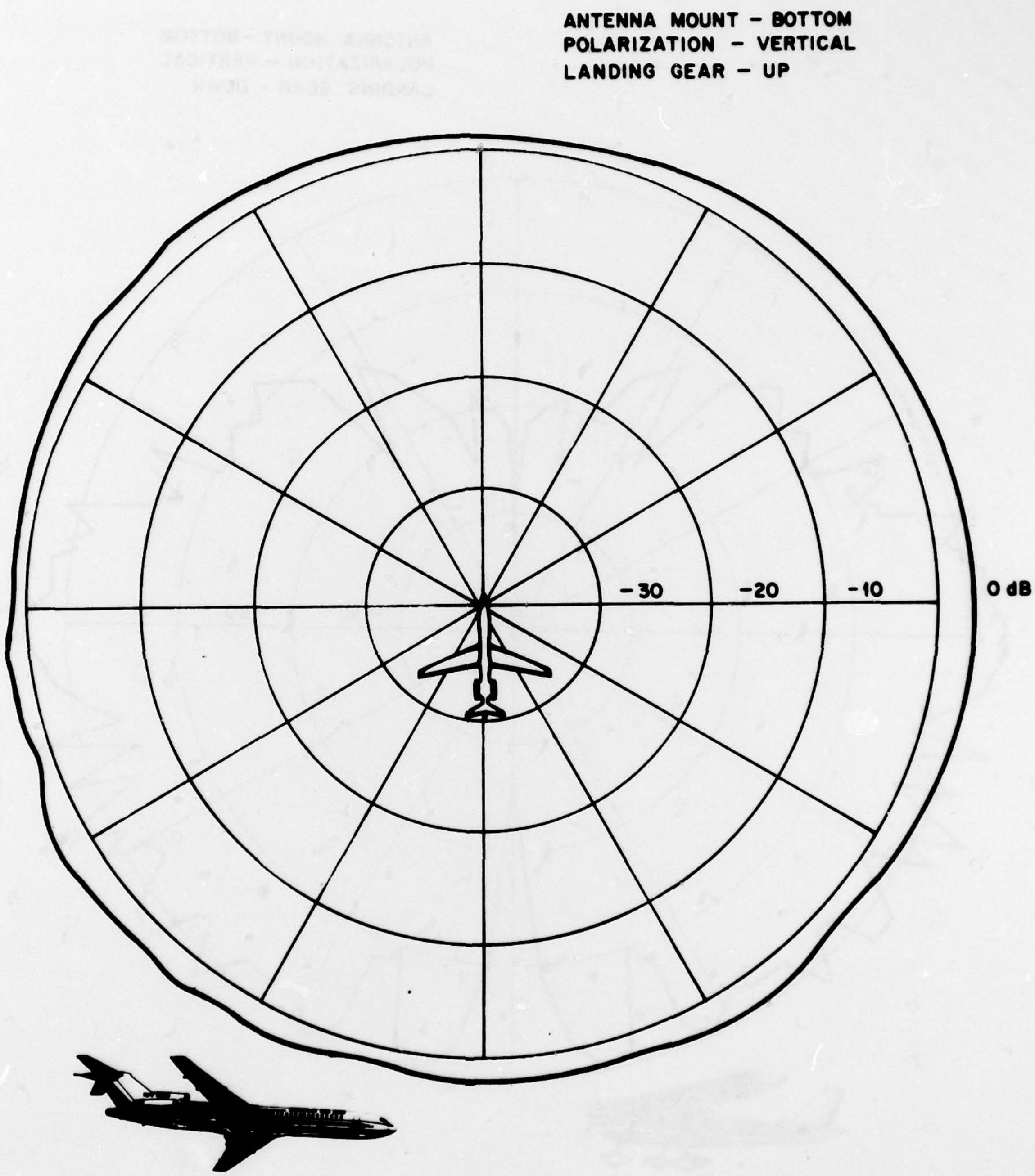

Figure B-6. Boeing 727 azimuth plane

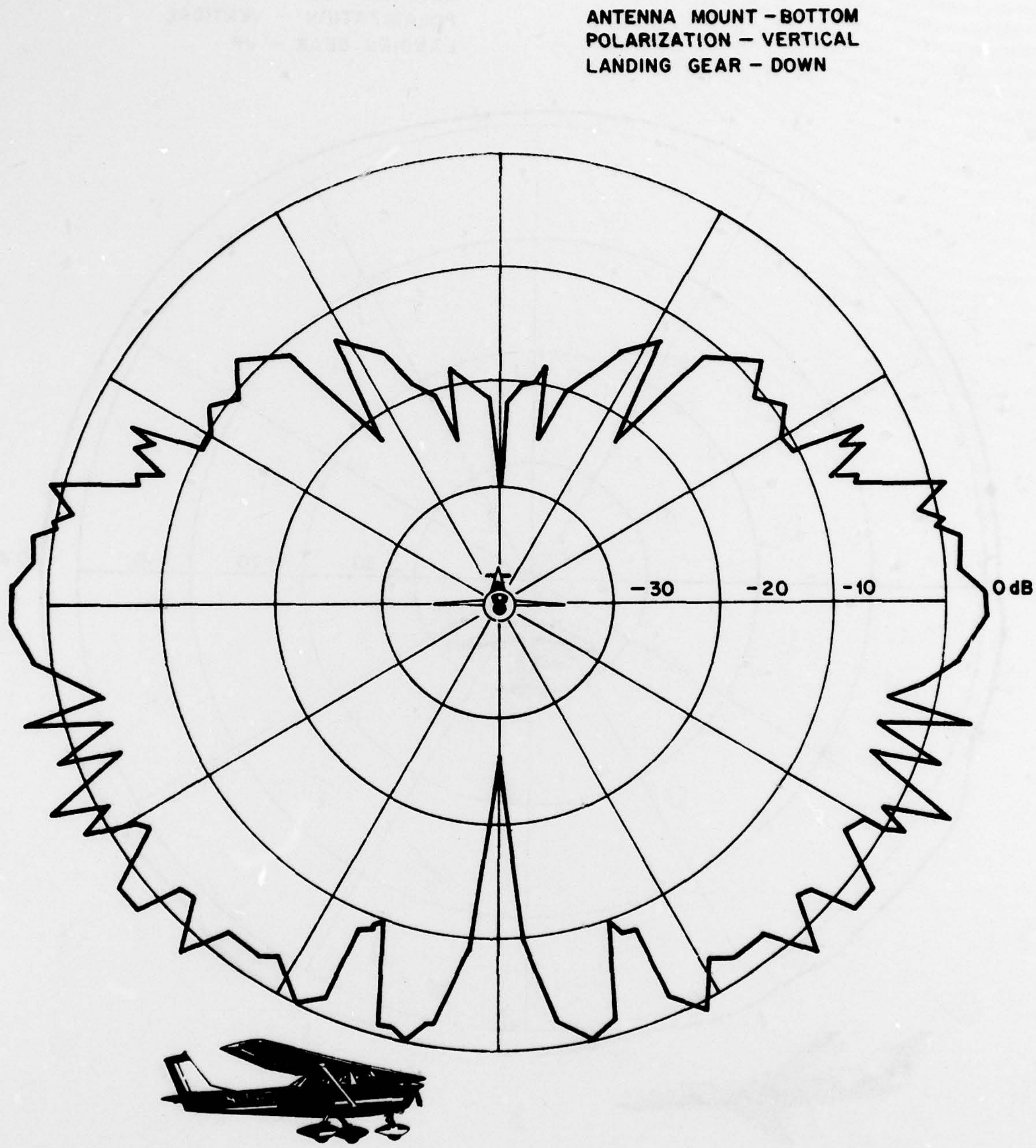

Figure B-7. Cessna 150 roll plane

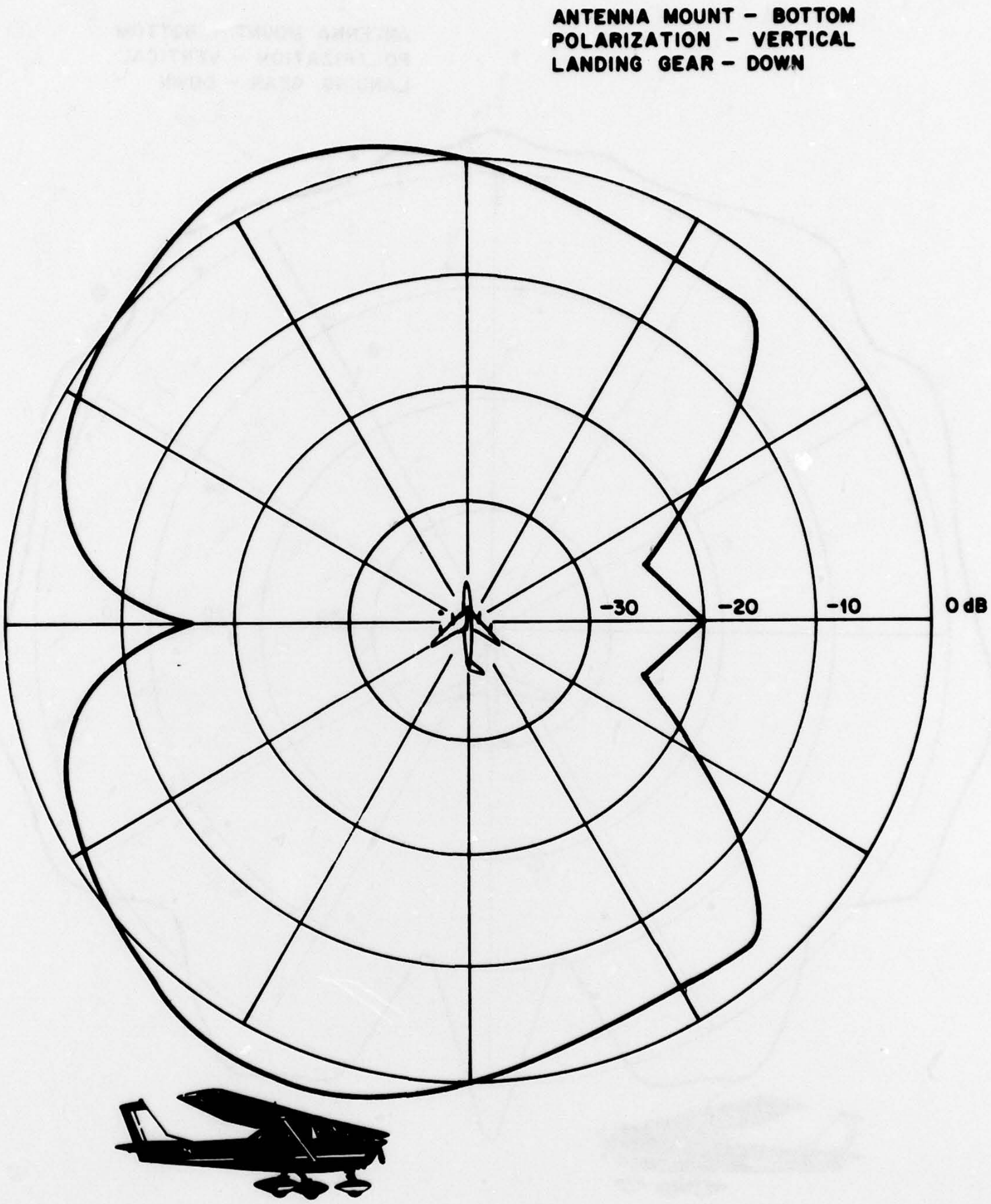

Figure B-8. Cessna 150 elevation plane

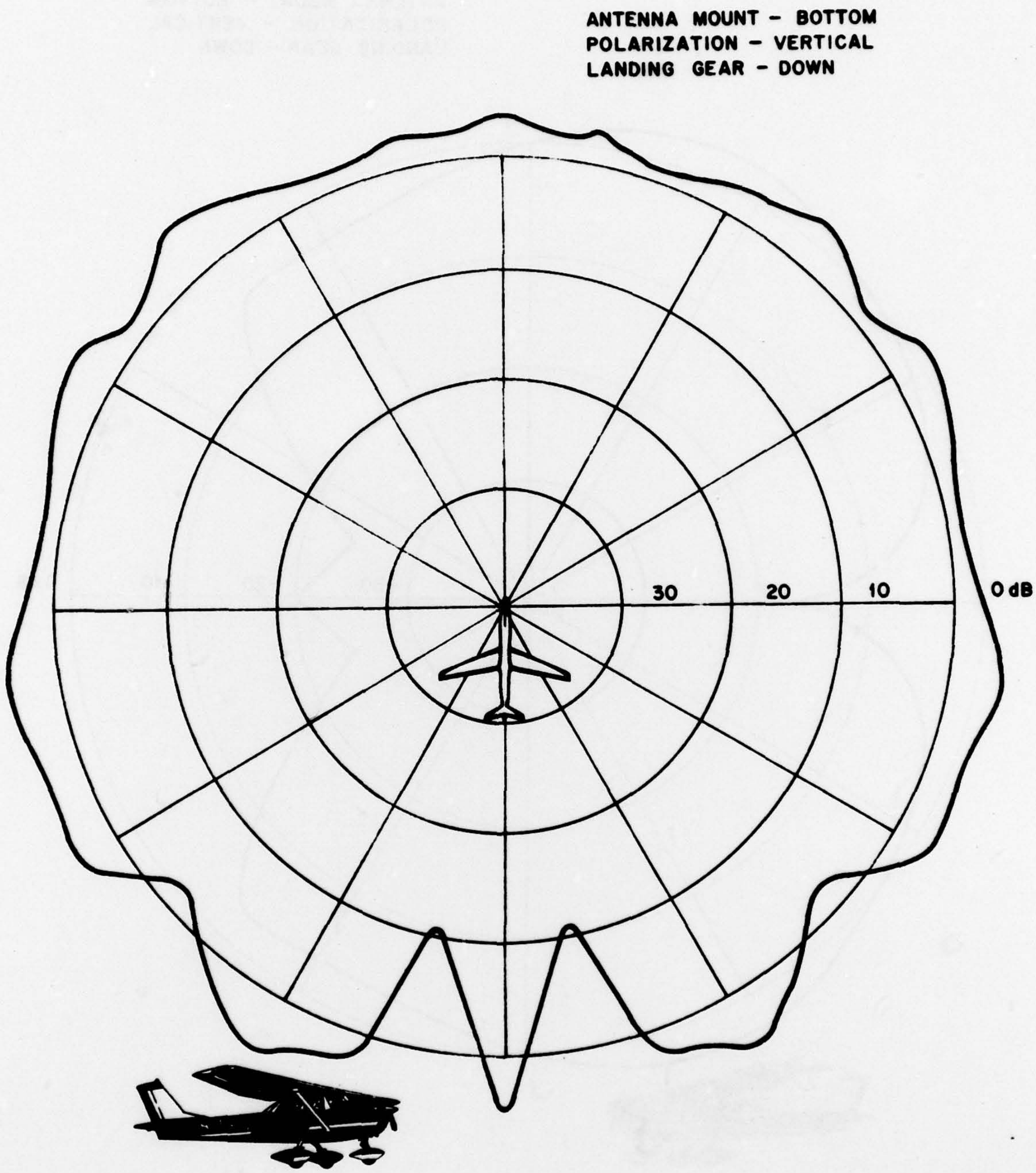

Figure B-9. Cessna 150 azimuth plane

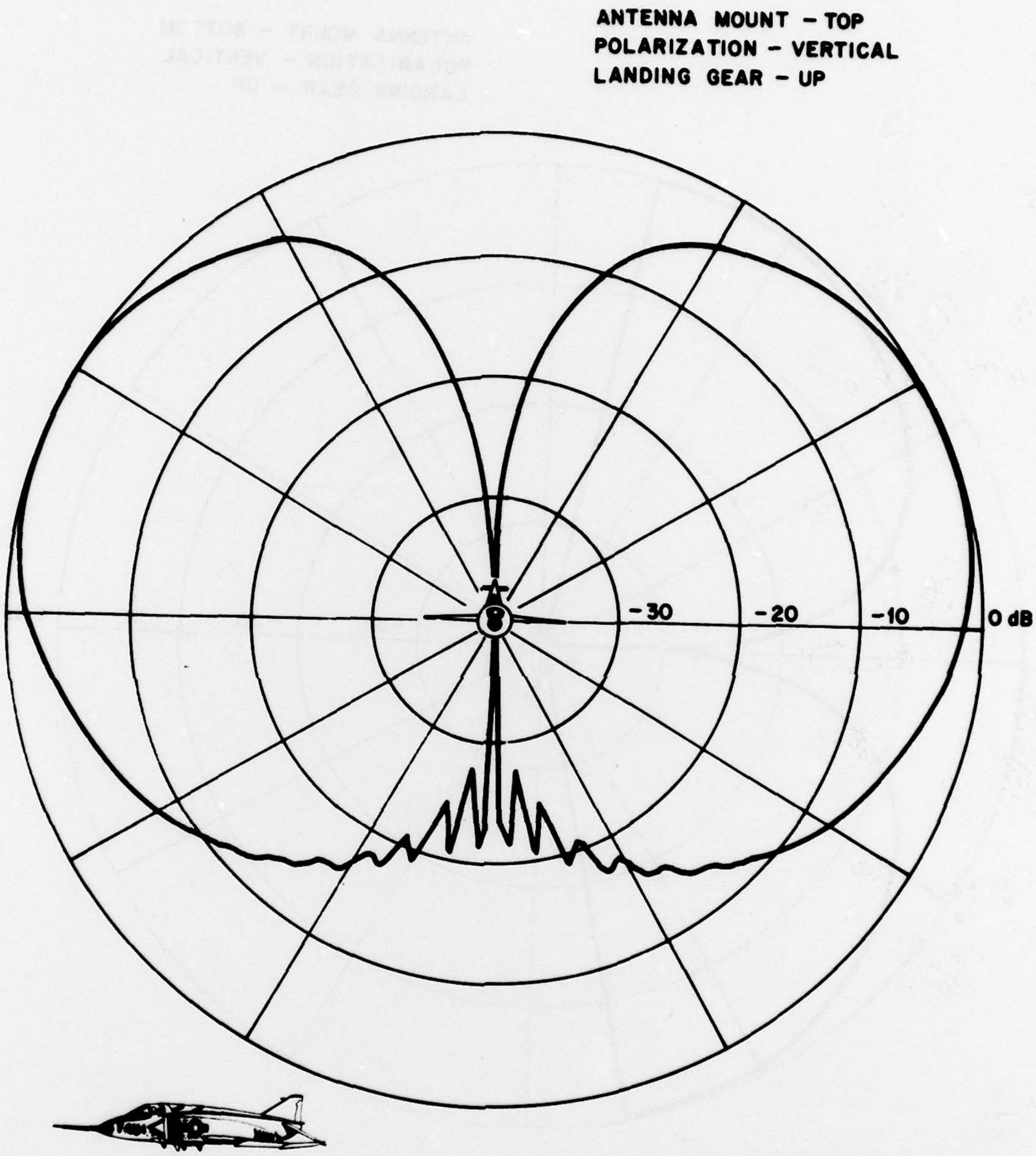

Figure B-10. F-4H roll plane

ANTENNA MOUNT – BOTTOM
POLARIZATION – VERTICAL
LANDING GEAR – UP

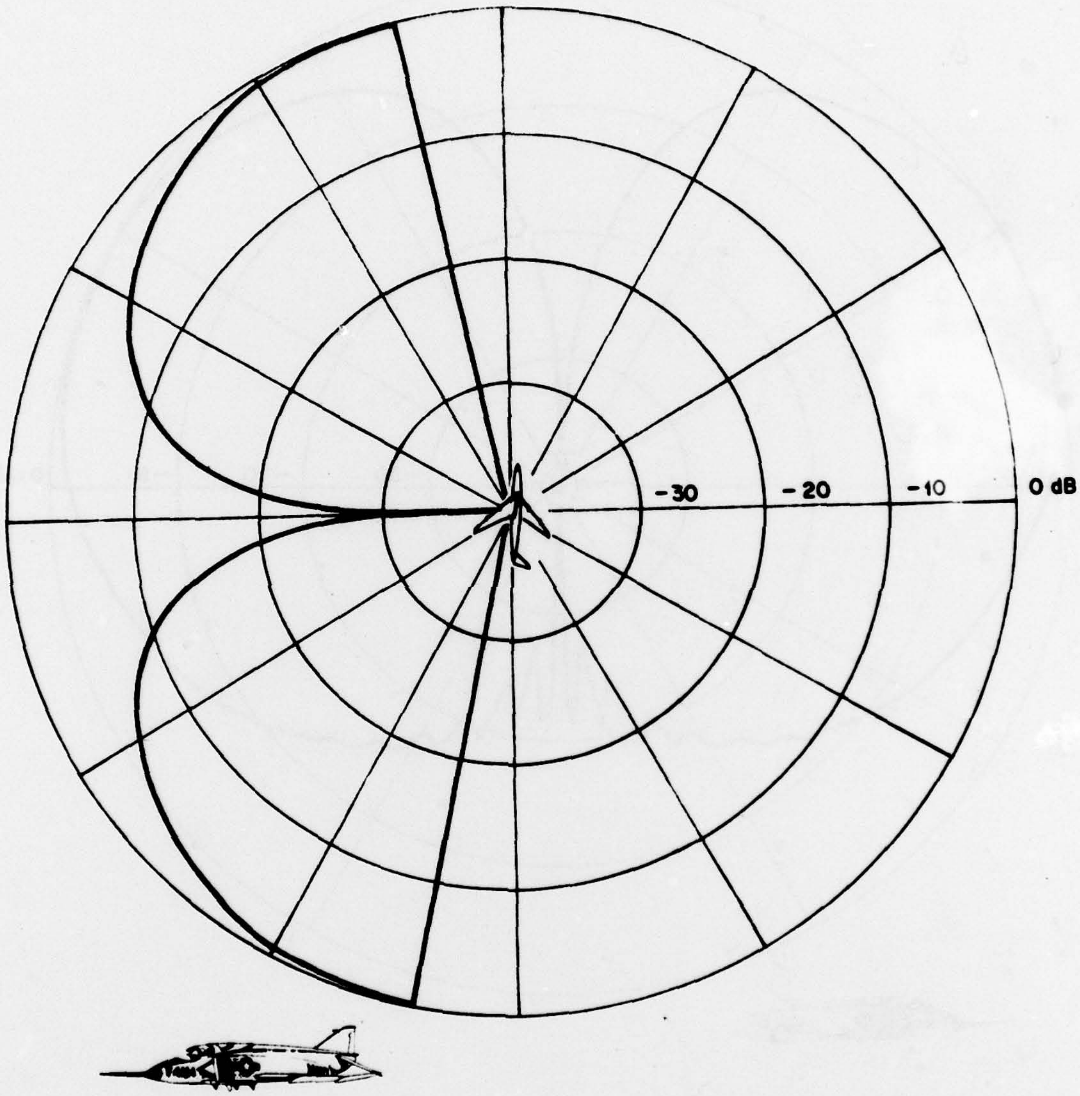

Figure B-11. F-4H elevation plane

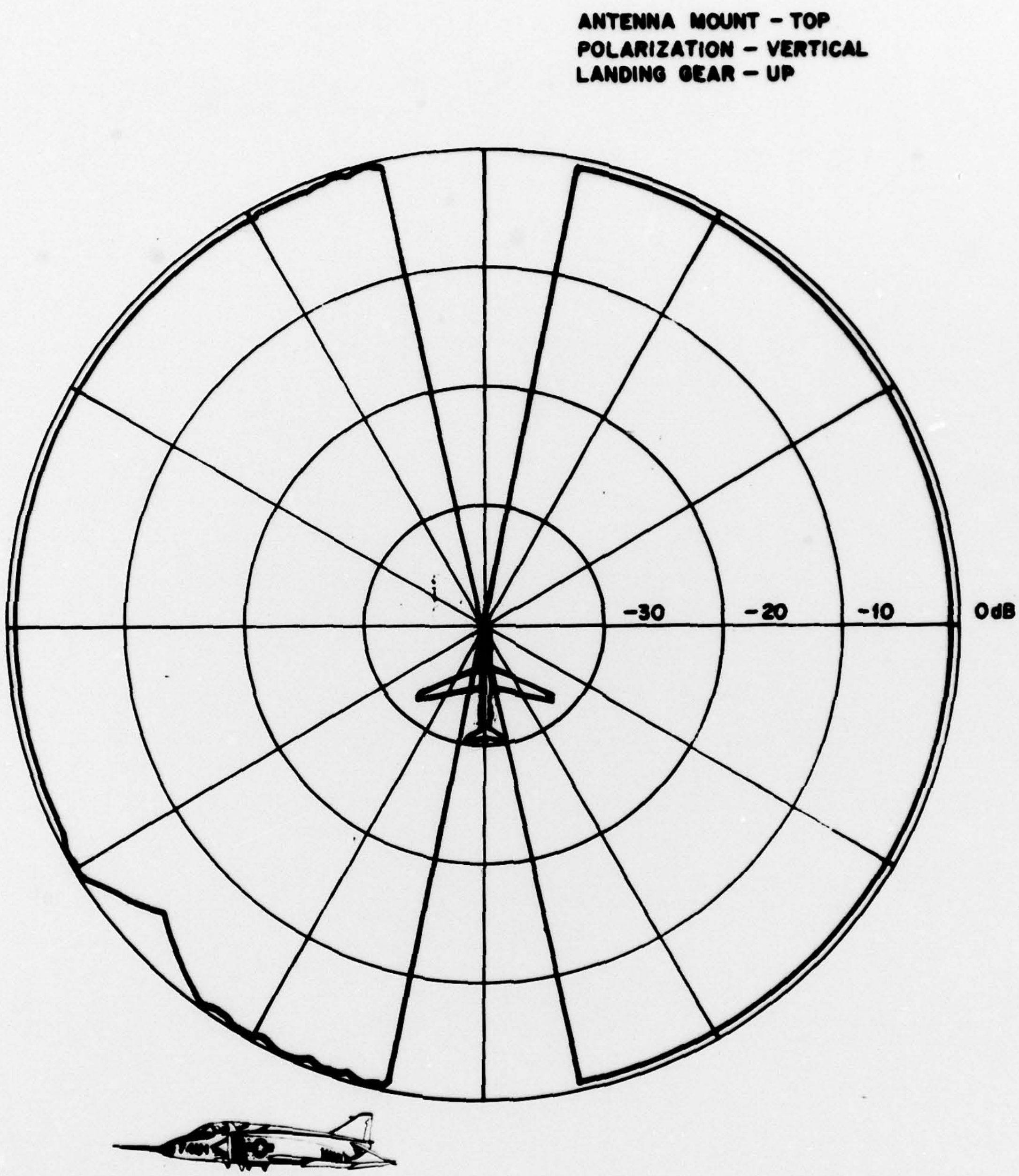

Figure B-12. F-4H azimuth plane